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THE EFFECT OF HIGH WING LOADING ON LANDING TECHNIQUE AND DISTANCE, WITH EXPERIMENTAL DATA FOR THE B-26 AIRPLANE

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WASHINGTON

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THE EFFECT OF HIGH WING LOADING ON LANDING TECHNIQUE AND DISTANCE, WITH EXPERIMENTAL DATA FOR THE B-26 AIRPLANE

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SUMMARY

An analysis of the effect of wing loading on the landing flare (that is, the leveling-off part of the landing) indicated an important effect on landing technique and distance. In order to check this analysis, flight tests were made with a Martin B-26 airplane loaded to 50 pounds per square foot. It was found that, for reasonable accuracy and safety, the pilots used power to maintain the desired speed margin and to limit the rate of descent at the start of the flare to about 25 feet per second. Other measured values essential to flare calculations include the following: minimum consistent value of excess speed at start of flare, 25 percent; maximum ratio of lift coefficient C_L to maximum lift coefficient $C_{L_{max}}$ consistently reached, 85 percent; time required to reach this C_L, 2 seconds; time required to reduce the C_L value to that for level flight at the end of the flare, 1 second. Since these allowances do not differ widely from those needed at low wing loadings (with the exception of the definite limitation of vertical velocity), it is concluded that the effect of an increase in wing loading on the flare path, for any airplane reasonably similar to the one tested, can be satisfactorily calculated.

INTRODUCTION

Increased wing loading, for purposes of landing-distance studies, requires primarily an increase in the value of stalling speed used, with consequent increase in the approach speed and the speed at ground contact. For the power-off condition, changes in lift-drag ratio L/D or maximum lift coefficient $C_{L_{max}}$ are secondary. If the landing technique remains unchanged, therefore, the size of field needed will increase markedly because of the higher horizontal velocities. The difficulty of exercising sufficient judgment in executing the landing flare (the leveling-off part of the landing), in order to avoid dangerous vertical velocities at the instant of contact, will also increase because of the increased vertical velocity in the approach. The analysis reported in reference 1 showed that the technique required for the shortest ground run was not affected by wing loading and that the length of the run increases in almost exact proportion to the wing loading. An analysis of the effect of loading on the landing flare, however, showed not only an increase in the horizontal distance from an altitude of 50 feet to the end of the flare but also an increase in the height at which the flare must be started. It was apparent from this analysis that some change in the technique used, either in the approach or in the flare or in both, was to be expected. In order to determine whether the theoretical flare calculations adequately represented the changes that the pilots found necessary, landing tests with an airplane of high wing loading were considered desirable. A B-26 medium-bomber airplane was used for these tests.

THEORETICAL TREATMENT PRIOR TO TESTS

Step-by-step calculations of the flare path were made for four stalling speeds and for four amounts of excess speed at the start of the flare, with the same glide angle, the same L/D, and the same lift coefficients assumed in all cases. The initial calculations were made on the assumption of an instantaneous change in C_L from the value used in the approach to a constant value maintained throughout the flare. A study of data on actual landings resulted in the modification of these calculations on the assumption that the lift-coefficient change occurred during an interval of 2 seconds and that the change occurred in the form of a sine wave.

These theoretical calculations indicated that increase in wing loading produces the following significant changes:

(1) The height at which the flare must be started increases almost directly with the wing loading.

(2) The time required for the maneuver increases as the square root of the wing loading.

(3) The loss in speed during the flare is a constant percentage of the stalling speed.

(4) The horizontal distance from a height of 50 feet to the end of the flare (that is, to the point at which zero vertical velocity is reached) increases about 35 percent if the wing loading is increased from 25 pounds per square foot to 50 pounds per square foot.

It was further obvious from general considerations that an error in the judgment of the pilot in executing the flare with an airplane of high wing loading would bring much more serious consequences than the same percentage error in technique with an airplane of low wing loading.

APPARATUS AND TESTS

The appearance and general arrangement of the Martin B-26 medium-bomber airplane may be noted in figures 1 to 3. The longitudinal axis of this airplane is identical with the thrust axis; dimensions and other details are as follows:

Attitude angle of longitudinal axis, static position, deg	0
Wing	
Area, total (including ailerons and fuselage), sq ft	602.0
Span, ft	65.0
Taper ratio (ratio of root chord to tip chord)	3:1
M.A.C., ft	10.2
Distance of leading edge of chord (M.A.C., rotated to parallel with thrust axis about quarter-chord point)	
Behind nose of airplane, ft	20.1
Above longitudinal axis, ft	1.8
Airfoil (root)	NACA 0017-64
Airfoil (tip)	NACA 0010-64
Angle of incidence (root and tip), deg	3.5
Dihedral (leading edge), deg	1.3
Flap (balanced split)	
Area, total effective (excluding projected areas through fuselage and nacelles), sq ft	58.1
Span, actual (including 7.4 ft through fuselage and 3.2 ft through each nacelle), ft	35.2
Chord (constant width), ft	2.7
Deflection from retracted position, maximum, deg	55.0
Ailerons (Frise)	
Area, total (one aileron including tab), sq ft	24.4
Span (one aileron), ft	13.8
Chord (hinge axis to trailing edge), percent wing chord	20.2
Deflection from position continuous with wing, deg	
Maximum up	19.1
Maximum down	14.7
Neutral position (up)	0.8
Fuselage	
Length, over-all, ft	58.2
Diameter, maximum (circular), ft	7.4
Angle with respect to longitudinal axis, deg	-1.0

Horizontal tail surface	
Area (including fuselage ahead of elevator hinge axis), sq ft	118.5
Span, ft	23.7
Angle of incidence of stabilizer, deg	1.0
Dihedral, deg	8.0
Elevator	
Area behind hinge axis (both elevators including tab), sq ft	41.1
Area ahead of hinge axis (both elevators), sq ft	12.9
Distance of hinge axis (at plane of symmetry)	
Behind nose of airplane, ft	51.4
Above longitudinal axis, ft	2.8
Maximum deflection, deg	
Up	20.0
Down	12.0

Vertical tail	
Area, total (excluding fuselage), sq ft	62.7
Span (excluding fuselage), ft	9.3
Rudder	
Area behind hinge axis (including tab), sq ft	26.2
Area ahead of hinge axis, sq ft	8.3
Distance of hinge axis behind nose of airplane (at root), ft	49.8
Maximum deflection, deg	±25.0

Landing gear (retractable tricycle)	
Distance between center lines of main wheels, ft	21.9
Wheel axle location (airplane static load, 28,512 lb)	
Main wheels	
Behind nose, ft	24.5
Below longitudinal axis, ft	5.8
Nose wheel	
Behind nose, ft	5.1
Below longitudinal axis, ft	6.4

Engines: Two engines, power rating (normal, one engine) 1500 bhp at 2400 rpm at 7500 ft

Propellers: 4 blades, 13.5-ft diameter; constant speed or manual pitch control; full feathering

Weight and center of gravity position	
Normal loading	
Weight, lb	28,512
Center of gravity (landing gear retracted)	
Crew at flight stations, percent M.A.C.	14.8
Crew at battle stations, percent M.A.C.	16.5
Maximum loading	
Weight, lb	31,421
Center of gravity (landing gear retracted and crew at flight stations), percent M.A.C.	16.9
Distance of c.g. below longitudinal axis (approximate; all conditions), ft	0.3
Height of c.g. above ground, airplane at rest, ft	7.2
Horizontal distance from c.g. to main wheels, airplane at rest, ft	2.6
Moments of inertia (approximate), slug-ft^2	
Pitch	76,000
Roll	70,000
Yaw	142,000

The airplane, as ballasted for most of the tests, had a wing loading of 50 pounds per square foot and a power loading of about 10 pounds per horsepower. In the first part of the tests, the airplane was somewhat lighter than these values indicate. The weight corresponding to each landing is shown in the summary table (table I).

All landings were made by NACA test pilots having wide experience with other types of airplane but no experience with the B-26 airplane prior to these tests. Although an attempt was made to cover a fair range of power settings and speed margins for the approach condition, the primary objective was to produce abrupt flares after an approach at the steepest angle and the lowest speed considered by the pilots to be reasonably safe; that is, the pilots attempted to use technique conducive to the shortest possible total run from a height of 50 feet. A number of landings also were recorded in which the personal choice of the pilots determined the technique used.

All landings were made at Langley Field, Va. Some tests were made between November 14, 1941, and December 7, 1941; the remainder of the tests were made between July 4, 1942, and August 15, 1942. All landings in the first series (referred to herein as the 1941 series) were made on bare, dry, concrete runways. Tests of the second series (referred to herein as the 1942 series) were made on concrete runways coated with camouflage material consisting of sawdust spread on an asphalt binder. The surface of the runways was sometimes moist from rains on previous days but was covered with water only in the instance noted in the summary table (table I).

Recording instruments installed during the 1941 series of tests included the following:

NACA three-component accelerometer
NACA rolling-velocity recorder
NACA pitching-velocity recorder
NACA airspeed recorder
NACA mechanical-optical control-position recorders arranged to record position of elevators, ailerons, rudder, throttles, and all three shock struts

The horizontal and vertical displacements and the attitude angle of the airplane were recorded by two phototheodolites stationed on the landing field. The phototheodolites and their uses are fully described in reference 2.

In the 1942 series of tests the following additional instruments were installed in the airplane:

NACA two-component accelerometer, normal and longitudinal elements (of greater sensitivity than the NACA three-component accelerometer)
Statoscope
Hydraulic pressure recorder connected to brake lines
Ciné-Kodak motion-picture camera for obtaining tire-deflection data in impact

The control-position recorders for ailerons, rudder, and shock struts were omitted during the 1942 series of tests.

The accelerometers and the angular-velocity recorders were placed at (or close to) the center of gravity of the airplane. All instruments in the airplane received timing impulses from a single NACA timer. Synchronization of the two phototheodolites with the instruments was effected by firing a flash bulb (visible in the phototheodolite records) in the nose of the airplane and simultaneously operating a solenoid that produced a break in a record line on one of the instruments.

PRECISION

The precision of the measurements is believed to be within the following limits:

Vertical displacement from phototheodolite, ft	±3
Horizontal displacement from phototheodolite, ft	±10
Vertical displacement from statoscope, ft	±10
Attitude angle, deg	±1.0
Vertical velocity, ft/sec	±3
Airspeed, miles/hr	±2
Manifold pressure, in. Hg	±0.5
Control surface angles, deg	±0.5
Pitching velocity, radian/sec	±0.005
Rolling velocity, radian/sec	±0.01
Normal acceleration, g	±0.05
Horizontal acceleration (two-component instrument), g	±0.03
Horizontal acceleration (three-component instrument), g	±0.05
Transverse acceleration, g	±0.04
Brake-line pressure, lb/sq in.	±10

These values are based on scatter of points, differences between original and reread values, and in some cases on comparison of results from different instruments or results obtained by different methods.

RESULTS

The results of the measurements are summarized in table I. The data are presented as time histories in figures 4 to 29. The time histories have been grouped according to the amount of data presented and the groups are introduced in the order of their significance to the study of the air runs. The time histories that are of primary interest in studies of landing approach and flare are given in figures 4 to 14. For convenience, the figure numbers corresponding to the various landings are listed in table I. At the speeds covered in these tests, the effects of compressibility are so small that the airspeeds given may be considered as either the observed airspeed corrected for installation and instrument errors or $V\sigma^{1/2}$ where V is the true airspeed and σ is the density ratio.

Examination of the time histories indicates that many of the records taken during the glide and flare, including the normal acceleration and the elevator position, are rather unsteady. Such unsteadiness is common in landing records. The degree of unsteadiness has been shown, in some previous tests, to be much greater in rough air than in smooth air. The degree of unsteadiness is also undoubtedly dependent to some extent on the degree of stability and the type of the control balance and the nature of the response of the particular airplane.

Results of glide-test measurements of the L/D of the airplane over a range of conditions appropriate to the various landings are given in figure 30. The values are termed "equivalent" L/D's because they include the effect of propeller thrust. Measurements of this kind were necessary for the theoretical treatment shown in figure 31.

DISCUSSION

Approach and Flare Path

Vertical velocity in approach.- It became apparent early in the tests that steady power-off approaches would result in vertical velocities, at the beginning of the flare, that equaled or exceeded the vertical velocity which the pilots could consistently handle with safety. The choice of a specific vertical velocity for the approach, above which too much safety and accuracy are lost, is necessarily somewhat arbitrary. Consideration of the comments of the pilots together with study of the data obtained, however, led to the choice of a value of 25 feet per second. The basis for the choice is most readily understood if the landings are considered in three separate groups.

(1) Power-off landings: Under the proper conditions and after sufficient experience had been obtained, the pilots made several landings in which the throttles were closed long before the end of the approach and were not reopened. In one instance, the throttles were closed at an altitude of 1500 feet and were not reopened. Values of vertical velocity up to 37 feet per second resulted at the start of the flare. These landings are considered exhibitions of piloting skill. The records indicate that, for these landings, the airplane tended to level off too high and to "balloon" (rise) at the end of the flare. This condition necessitated a second approach and flare of smaller proportions. (See figs. 4 and 9.)

(2) Power-on landings: For comparison with power-off landings, a number of landings were recorded in which the pilots used considerable power (manifold pressure, about 20 inches of mercury) and started the flare with vertical velocities of about 15 to 20 feet per second. During these landings there was no tendency to balloon and in several instances ground contact was made without completing the flare but without any abnormal shock in impact. (See figs. 7, 21, and 24 and table I.) These landings include landings in which the pilot was not following any special instructions and was using the technique that he felt provided the greatest safety.

(3) Landings with moderate power: In the majority of landings the pilots made the approach with the highest vertical velocity considered reasonably safe. Manifold pressures of about 10 to 12 inches of mercury were used in the approach and the flare was started with a vertical velocity of 20 to 30 feet per second. The accuracy with which the flare was completed appears marginal in these landings; that is, some records showed a tendency for the airplane to level off too high and to balloon, while others did not, with no definite correlation with the vertical velocity apparent.

Consideration of these three groups of landings indicates the following conclusions: The power-off landings, with vertical velocities of 30 to 40 feet per second, are in no sense practicable or common maneuvers. The power-on landings, with vertical velocities of 20 feet per second and less, produce accurate flares that cause no necessity for an additional maneuver before making ground contact. The accuracy and practicability of the landings with intermediate power settings and vertical velocities between 20 and 30 feet per second are marginal. The average of the marginal values, 25 feet per second, is considered a rational limiting value for use in flare calculations.

Speed margin in approach.- Calculations of the flare path require also an assumed speed margin. The excess speed maintained in the approach during the various landings is given in table I as a percentage of the stalling speed (as obtained from measurements at altitude) for the corresponding power and flap settings. If allowance is made for the fact that the landings made at the highest power settings were not strictly test landings and that the pilot was allowing a greater margin of safety than in the other landings, a tendency toward the reduction of the speed margin with increase in power setting and decrease in vertical velocity is then apparent. The fact that the power-on approaches, with low vertical velocity, were made with outstandingly low horizontal velocities results to a large extent from the higher maximum lift coefficients which apply to the power-on condition. It is common in piloting experience to find that the stalling speed is much lower with power on than with power off and is immediately increased when the power is reduced. Application of power in making landings therefore makes possible both a slower approach and a more rapid lift reduction for a "spot" landing than could be obtained with power off.

Consideration of the purpose and the conditions for the various landings resulted in the selection of a value of 25 percent of the stalling speed as a logical value of excess speed for use with an assumed vertical velocity of 25 feet per second. It is noteworthy in this connection that, when a flare was begun with 21 percent excess speed, the airplane stalled prior to completion of the flare (landing 7, 1942; see fig. 6).

Percent of $C_{L_{max}}$ used in landing flare.- The maximum ratio of C_L to $C_{L_{max}}$ used in the leveling-off period has been tabulated in table I for the various landings. Because the power setting usually was changed during the flare, the values used for $C_{L_{max}}$ often do not correspond to the stalling speeds used in calculating the speed margin in the approach. No correlation of ratio of C_L to $C_{L_{max}}$ with vertical velocity of approach, or any other factor, is apparent. Values of this ratio of about 90 percent usually were reached in the tests. These values are peak values; inspection of the time histories indicates 85 percent to be a logical value for use in any calculations which require that the value be sustained for an appreciable period. This value of 85 percent is slightly less than the actual average but, in view of the obvious seriousness of stalling during a flare started at high vertical velocity, a margin of 15 percent would seem the lowest value that should be suggested for consistent use.

Time required to change C_L.- Inspection of the time histories leads to an assumption of 2 seconds for the time required to increase C_L from the value used in the approach to the maximum value used in the flare and 1 second for the time required to reduce C_L to the value for steady level flight at the end of the flare.

Examples of theoretical calculations.- A theoretical flare time history based on the assumptions for vertical velocity, excess speed, and time required to change C_L is shown as condition (a) on figure 31. The value of L/D used is based on the approach angle as determined by the rate of descent and approach velocity. Glide tests made at altitude with the same power and flap settings (see fig. 30) gave a value in good agreement with this value and showed the L/D to be nearly constant over the full range of lift coefficients used in the flare. For comparison with the theoretical time history, values taken from the experimental data of figures 6 and 8 have been plotted on the figure.

In order to show the extent to which the pilots' use of a value of C_L less than $C_{L_{max}}$ affects the path, a theoretical time history for the same approach conditions but with the entire flare made at $C_{L_{max}}$ is given in figure 31 (condition (b)).

Because the margins of speed and lift coefficient found in these tests are consistent with those experienced with airplanes of lighter loading, it is believed that the effect of a moderate further increase in loading can be calculated with fair accuracy. In order to illustrate the application of the theoretical treatment to higher wing loadings, the same assumptions as used in condition (a) of figure 31 for vertical velocity, excess speed, C_L, and time required to change C_L have been applied to a hypothetical airplane with 50 percent higher loading. The resulting time history is shown as condition (c) in the same figure.

Possible variation of assumptions.- The applicability of the assumptions based on these tests to any particular case is conditioned by the following considerations:

The maximum practicable rate of descent will vary somewhat according to the degree of experience and ability of the pilot.

The percentage of excess speed needed in the approach may be reduced slightly with further increase in loading, since the vertical velocity to be checked will not be increased further. This result follows from the fact that, when the vertical velocity is assumed to increase in proportion to the loading, the percentage of excess speed required remains constant.

The maximum lift coefficient reached in the flare will vary with the pilots' experience and conservatism. The pilot, in addition, must allow a greater margin if he is flying an airplane that rolls unexpectedly, has a rapid decrease in L/D as the stall is approached, or otherwise has unfavorable characteristics at or near the stall.

The 2-second interval used to reach the maximum value of C_L attained in the flare has previously been observed with airplanes of lower loading than the airplane used in the present tests and widely different general characteristics. Since the records of elevator movement show that only a fraction of the available elevator travel is used, the length of the interval appears to be determined by the preference of the pilot rather than by any limitation of available pitching moment. Since these data include landings made by three different pilots, the value would seem to be reasonably general.

The time used to reduce C_L to that for steady level flight at the end of the flare varied more than any other factor. This result might be expected since this period provides the final opportunity to correct for errors or the effect of unpredictable changes in wind conditions. In some cases the flare was terminated by ground contact without the need of the 1-second period of adjustment, but this termination cannot be counted upon as a regular procedure following an abrupt flare. The chief effect of the period of adjustment used in ending the flare is to increase the horizontal distance consumed; the effect of this period of adjustment on the height at which the the flare must be started is negligible.

Technique for shortest total landing run.- It should not be taken for granted that the use of the maximum value of rate of descent which the pilot is willing to use will result in the shortest practicable landing. Inspection of the data obtained indicates that the shortest total distance from a height of 50 feet to a stop, even under emergency conditions, will be obtained by the use of more power, and hence lower vertical velocity, than the amount which corresponded to what the pilots considered reasonable limitations. The use of more power and lower vertical velocity shows two advantages: (1) greater accuracy in completing the flare and (2) lower speed at the end of the flare. The exact point at which the effect of these advantages ceases to offset the effect of the flattening of the glide path would, of course, be very difficult to determine even for a given airplane, pilot, and runway surface.

Ground Run

The data presented for the ground runs have not been analyzed in detail but examination indicates that treatment similar to that given in reference 1, including the 2-second transition time between ground contact and brake application (used in the examples), would provide reasonable values for the length of the shortest possible ground run. The experience gained in the tests served, however, to emphasize the fact that maximum braking is strictly an emergency procedure rather than a practicable routine procedure and that the brakes must be in proper condition if such a stop is to be made. During the second series of tests an unequal braking action existed, the cause of which was not determined and corrected until after landing 14.

The brakes showed a lag of approximately 1 second upon initial application. Since the pilots do not apply the brakes prior to nose-wheel contact with an airplane of this type (particularly when the nose is already descending rapidly), the effect of this lag is to increase the minimum length of run by about 150 feet.

CONCLUSIONS

Flight tests, which were made to verify an analysis of the effect of wing loading on the landing flare (the leveling-off part of a landing), indicated the following conclusions:

1. Considerations of safety and accuracy limit the rate of descent used in the landing approach to about 25 feet per second.

2. When the wing loading and lift-drag ratio are such as to produce a value in excess of 25 feet per second in a power-off glide at the minimum speed considered safe, the rate of descent is reduced to 25 feet per second or less by application of power by the pilot.

3. For the B-26 airplane operated at a wing loading of 50 pounds per square foot, the height at which the pilot must begin the flare, the horizontal distance from 50 feet altitude to the end of the flare, and the excess speed at ground contact can be determined satisfactorily by simple calculations based on a rate of descent of 25 feet per second and including normal speed, time, and lift-coefficient margins.

4. The results obtained in the investigation are believed to be applicable for calculations of the effect on the approach and flare path of further increases in wing loading.

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TABLE I

SUMMARY OF LANDING-RUN MEASUREMENTS

Landing	Figure	Flap setting (deg)	Weight at landing (lb)	c.g. position (percent M.A.C.)	Vertical velocity in approach (fps)	Approach manifold pressure (in. Hg)	Time of throttle cut before contact (sec)	$V\sigma^{1/2}$ (mph)			Maximum C_L used in flare	Corresponding $C_{L_{max}}$	Maximum ratio of C_L to $C_{L_{max}}$ in flare	Excess speed at end of approach (percent stalling speed)	Horizontal distance (ft)				Ground wind (mph)		Pilot	Remarks
								End of approach	End of flare	At contact					Height of 50 ft to end of flare	End of flare to contact	Ground run	Height of 50 ft to stop	Parallel to runway	Across runway		
1941 series																						
1	----	35	------	------	--------	--------	6	149	-----	112	-----	-------	--------	--------	--------	-------	3000	------	--------	------	A	Familiarization flight
2	----	35	27,600	20.5	--------	14	$^a3$	138-135	-----	109	-----	-------	--------	33-30	--------	-------	2200	------	6	3	A	^{b}Normal landing
3	----	35	27,600	20.5	--------	14	$^a6$	130	-----	115	-----	-------	--------	25	--------	-------	2760	------	3	1	A	^{c}Enough lift to check V_v
4	----	35	27,600	20.5	--------	10	7, -½	135-130	-----	108	-----	-------	--------	27-22	--------	-------	------	------	6	2	A	
5	----	35	27,600	20.5	--------	17	9, ½	138-140	-----	117	-----	-------	--------	34-36	--------	-------	------	------	--------	------	A	
6	10	35	27,700	20.5	--------	12	8,0	130	115	106	1.50	1.53	0.98	23	--------	-------	2450	------	8	3	A	^{c}Nose very high in landing
7	----	35	27,500	20.0	25	10	7	140	129	112	1.40	1.58	.89	32	700	1010	2730	4440	10.5	4.3	A	
8	15	35	27,200	20.0	29-24	9	7,-1,-4	136	123	116	1.35	1.53	.88	29	650	360	2760	3770	12.1	6.4	A	
9	11	35	27,500	20.0	--------	11	2	135	123	113	1.30	1.50	.86	27	--------	-------	3650	------	2	0	A	
10	16	35	27,200	20.0	29-18	10	9	135	118	104	1.35	1.50	.90	28	760	890	1260	2910	2	1	A	
11	12	35	26,800	20.0	--------	0-6	50	145-150	130	113	1.15	1.50	.77	35-39	--------	-------	2700	------	2	1	A	^{c}No trouble to check V_v
12	13	35	27,400	20.0	--------	0-6	--------	141	127	112	1.35	1.50	.90	30	--------	-------	1870	------	1	0	A	^{c}Felt just able to check V_v
13	4	35	27,900	20.5	29	0-6	12	140	128	111	1.35	1.50	.90	27	700	1040	2400	4140	4.2	1.7	A	^{c}Contact just at stall
14	14	35	26,000	19.0	--------	9	10	140	124	107	1.20	1.58	.76	37	--------	-------	1525	------	20	------	A	^{b}Normal landing
1942 series																						
1	17	35	29,200	17.5	--------	22	$^a7$	132	125	120	1.40	1.62	0.86	31	--------	-------	------	------	--------	------	B	^{b}Normal landing
2	----	55	28,600	17.0	--------	23	$^a16$	--------	-----	111	-----	------	--------	--------	--------	-------	------	------	--------	------	B	^{b}Normal landing
3	----	55	29,200	17.5	--------	21	4	--------	-----	121	-----	------	--------	--------	--------	-------	------	------	--------	------	B	^{b}Normal landing
4	18	35	30,500	18.5	21	15	4	127	120	108	1.45	1.80	.80	21	--------	-------	3650	------	9	-4	C	
5	19	35	30,000	18.0	30	10	3	136	128	110	1.40	1.70	.82	27	610	630	3470	4710	5	2	C	
6	5,26	35	30,600	18.5	29	10	5	135	123	115	1.60	1.62	.99	25	710	550	3980	5240	7	2	C	
7	6,27	35	30,400	18.5	26	10	-1	130	$^d118$	118	$^d1.65$	1.70	$^d.97$	21	580	0	4170	4750	3	1	C	
8	20	35	30,700	18.5	28	10	2	130	119	110	1.73	1.70	1.02	20	--------	-------	2870	------	4	8	C	
9	----	35	30,500	18.5	28	10	5	138	125	108	1.55	1.70	.91	28	640	900	2570	4110	3	7	C	
10	21	35	29,900	18.0	22-14	22	$^a7$	130	117	117	1.55	1.70	.91	32	--------	-------	3850	------	--------	------	C	^{b}Normal landing (runway covered with water)
11	7	55	30,700	18.5	18-15	20	4	126	115	114	1.70	1.65	1.03	28	810	0	2730	3540	4	4	B	
12	8,28	55	30,300	18.5	23	13	4	139	128	121	1.45	1.65	.88	35	760	280	3000	4020	0	1	B	
13	9,29	55	30,000	18.0	37	0-6	Closed before record start	143	132	119	1.40	1.65	.85	31	630	770	3070	4470	4	4	B	
14	22	35	30,300	18.5	17-13	15	1.5	130	120	117	1.45	1.62	.89	25	680	0	2060	2740	6	3	A	Power-on approach requested
15	23	35	30,200	18.0	12	20	11,-3,5	123	117	117	1.55	1.75	.89	24	--------	-------	4080	------	3	-5	A	
16	24	55	30,000	18.0	16	15	1.5	121	115	115	1.60	1.65	.97	16	--------	-------	4150	------	2	-1	A	
17	25	55	29,700	18.0	20	12	4	130	115	109	1.40	1.80	.78	26	1070	0	4350	5420	5	4	A	
18	----	55	29,400	17.5	--------	12	--------	--------	-----	$^e106$	-----	------	--------	--------	--------	-------	------	------	8	5	A	

[a] Power eased off following this time.
[b] "Normal landing" means no special instructions given to pilots.
[c] From pilot's notes; V_v, vertical velocity.
[d] Airplane stalled prior to completion of flare.
[e] From ground speed, wind speed, and density ratio.

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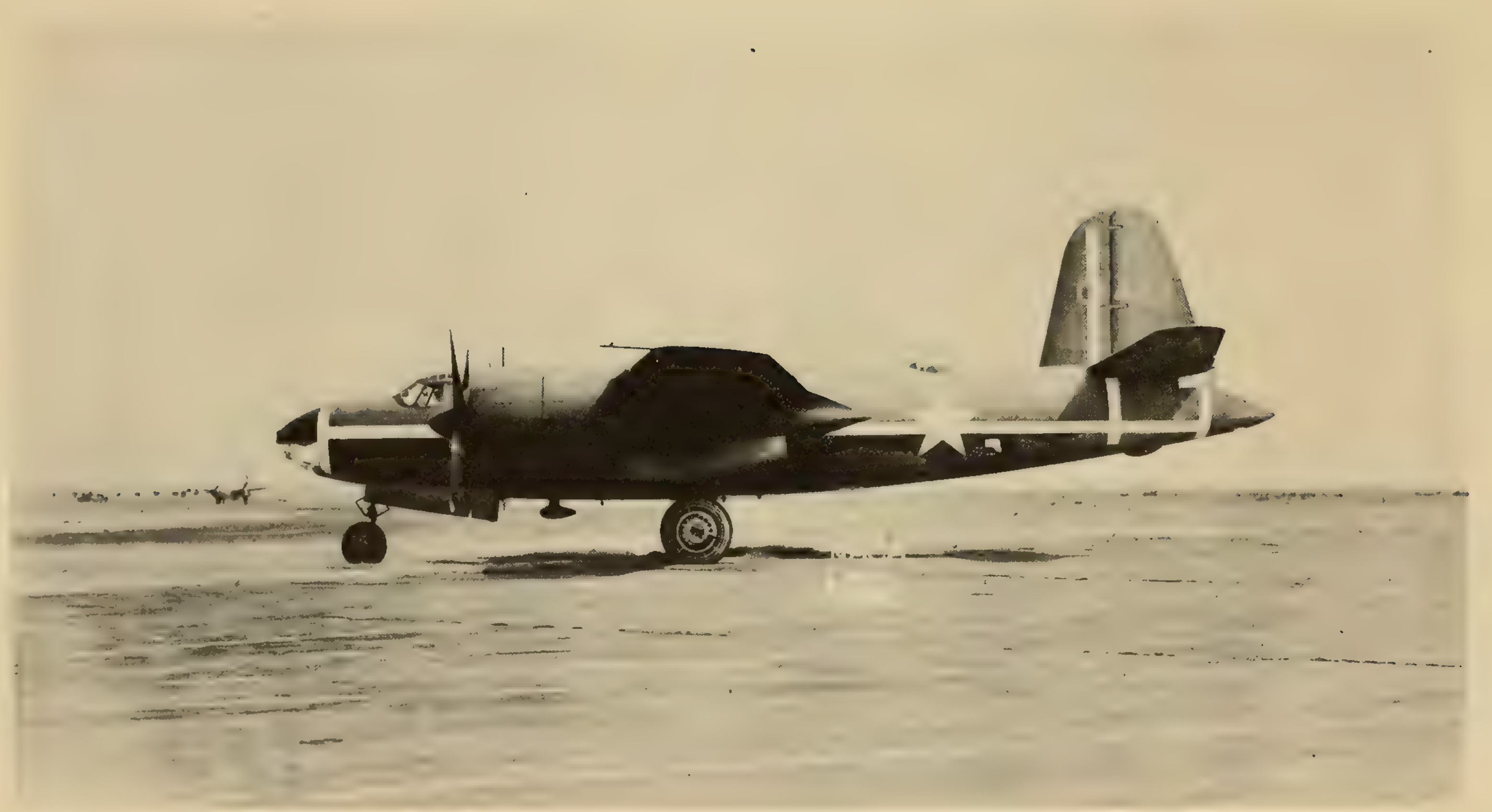

Figure 2.- B-26 airplane, side view.

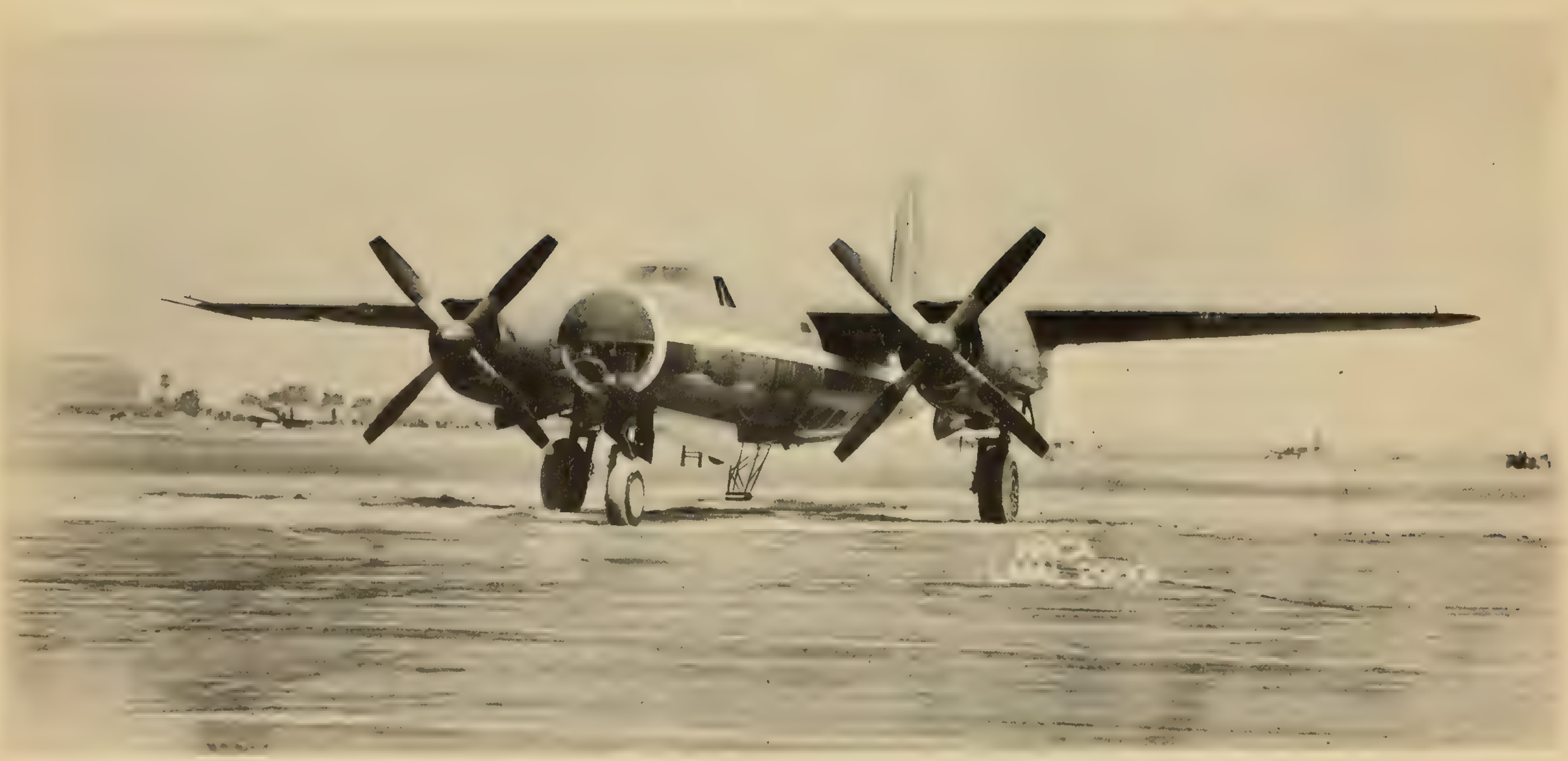

Figure 3.- B-26 airplane, front three-quarter view.

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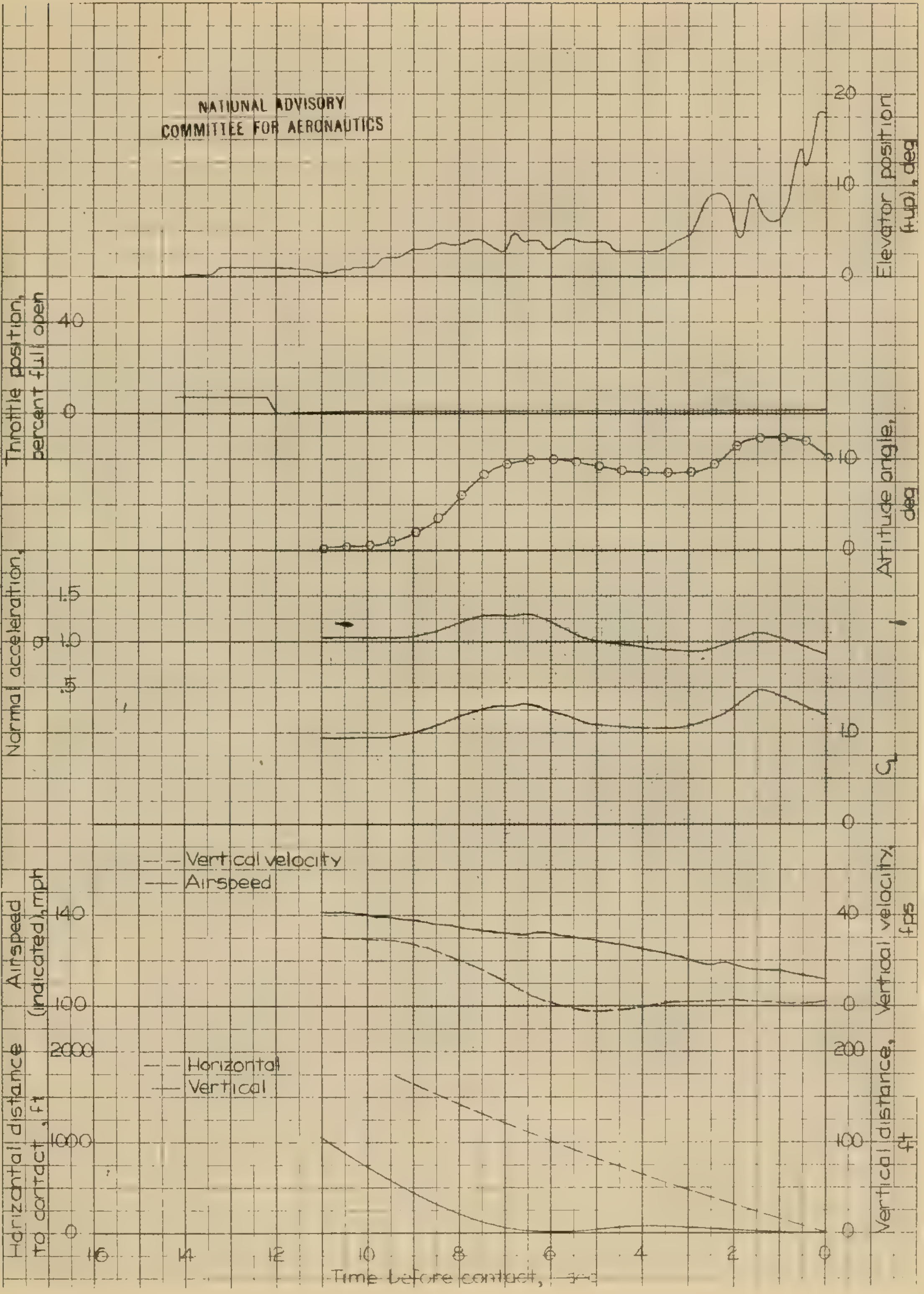


Figure 4.- Time history of landing approach and flare. B-26 airplane; landing 13, 1941 series.

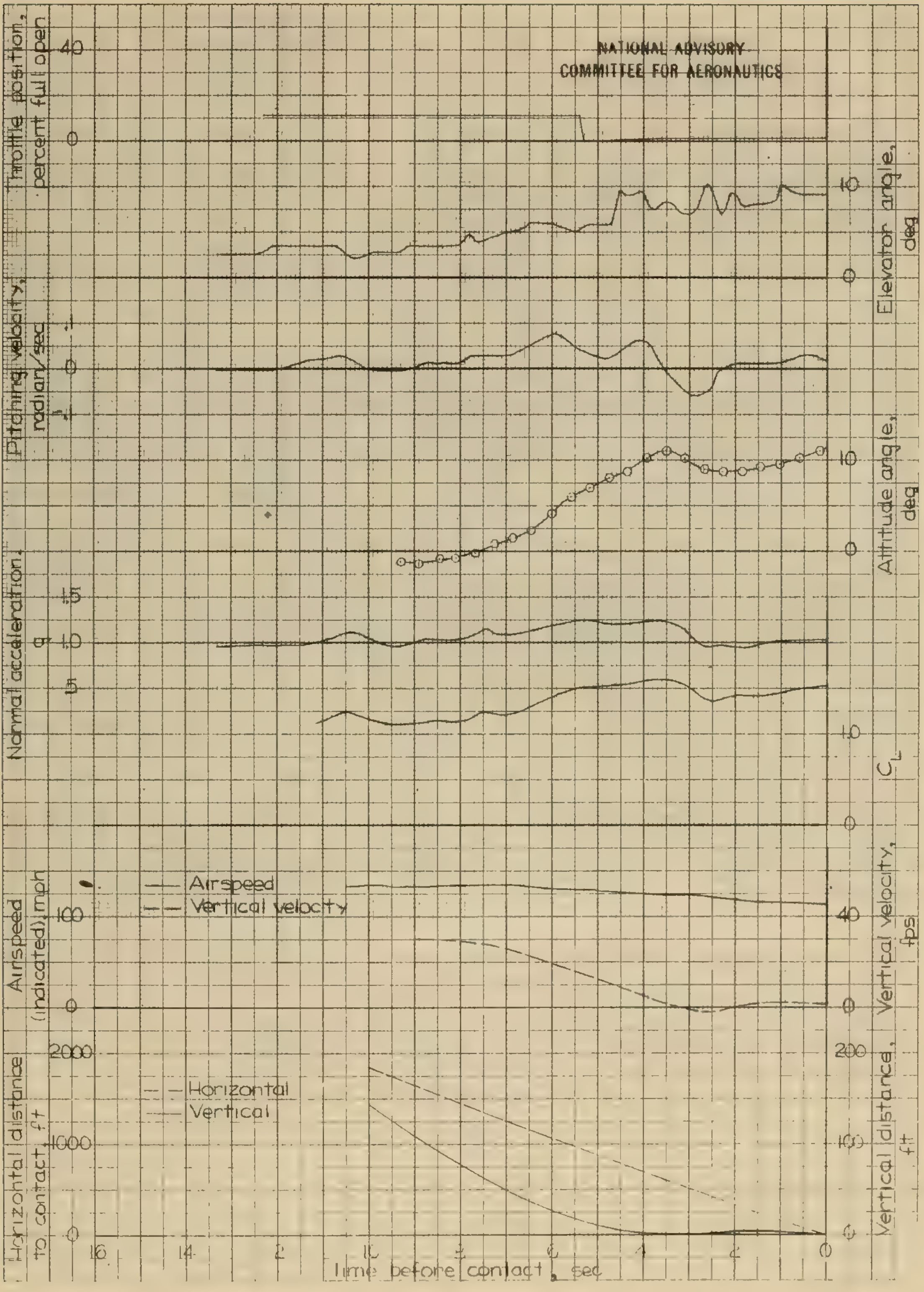


Figure 5.- Time history of landing approach and flare. B-26 airplane; landing 6, 1942 series.

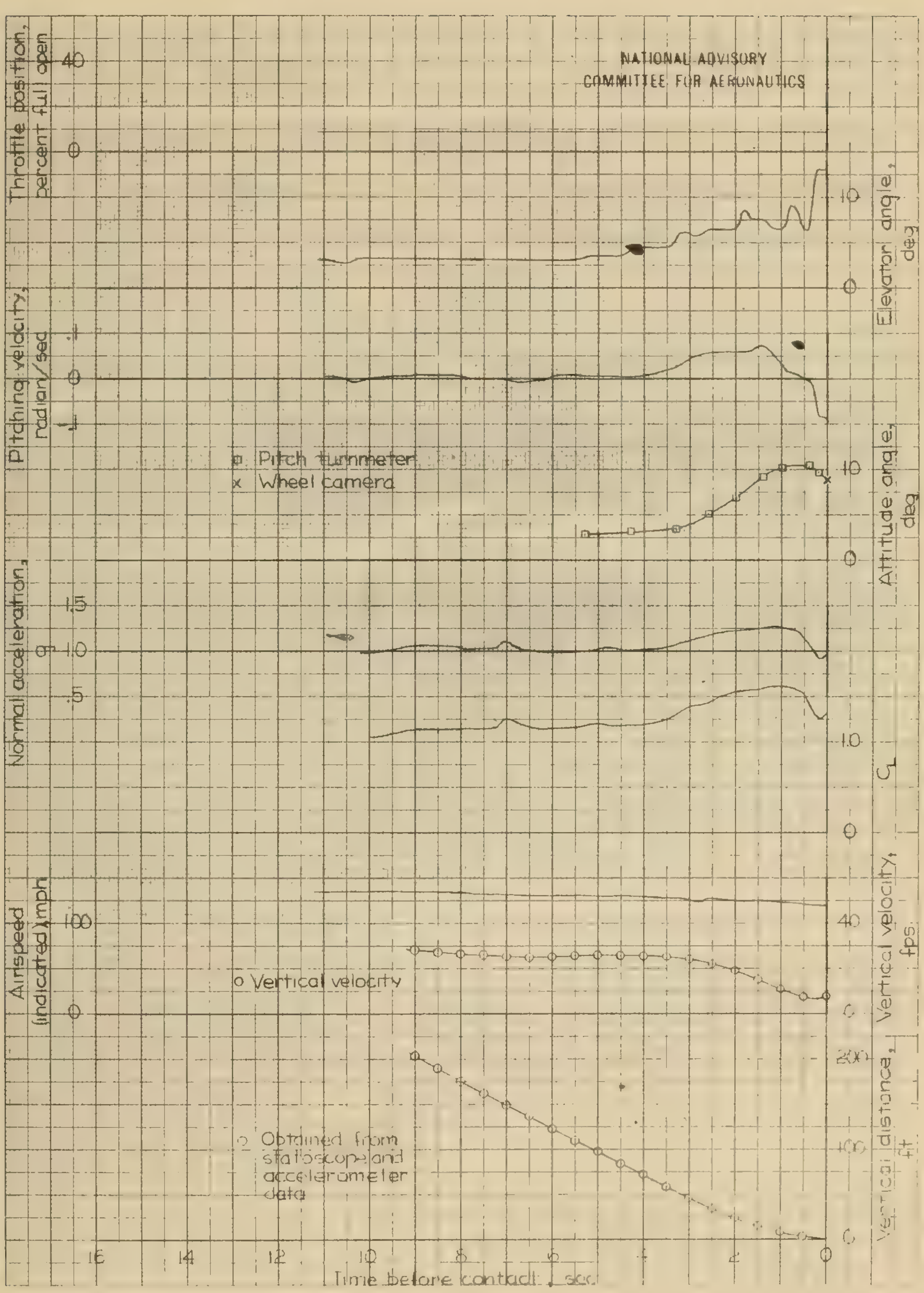


Figure 6.- Time history of landing approach and flare. B-26 airplane; landing 7, 1942 series.

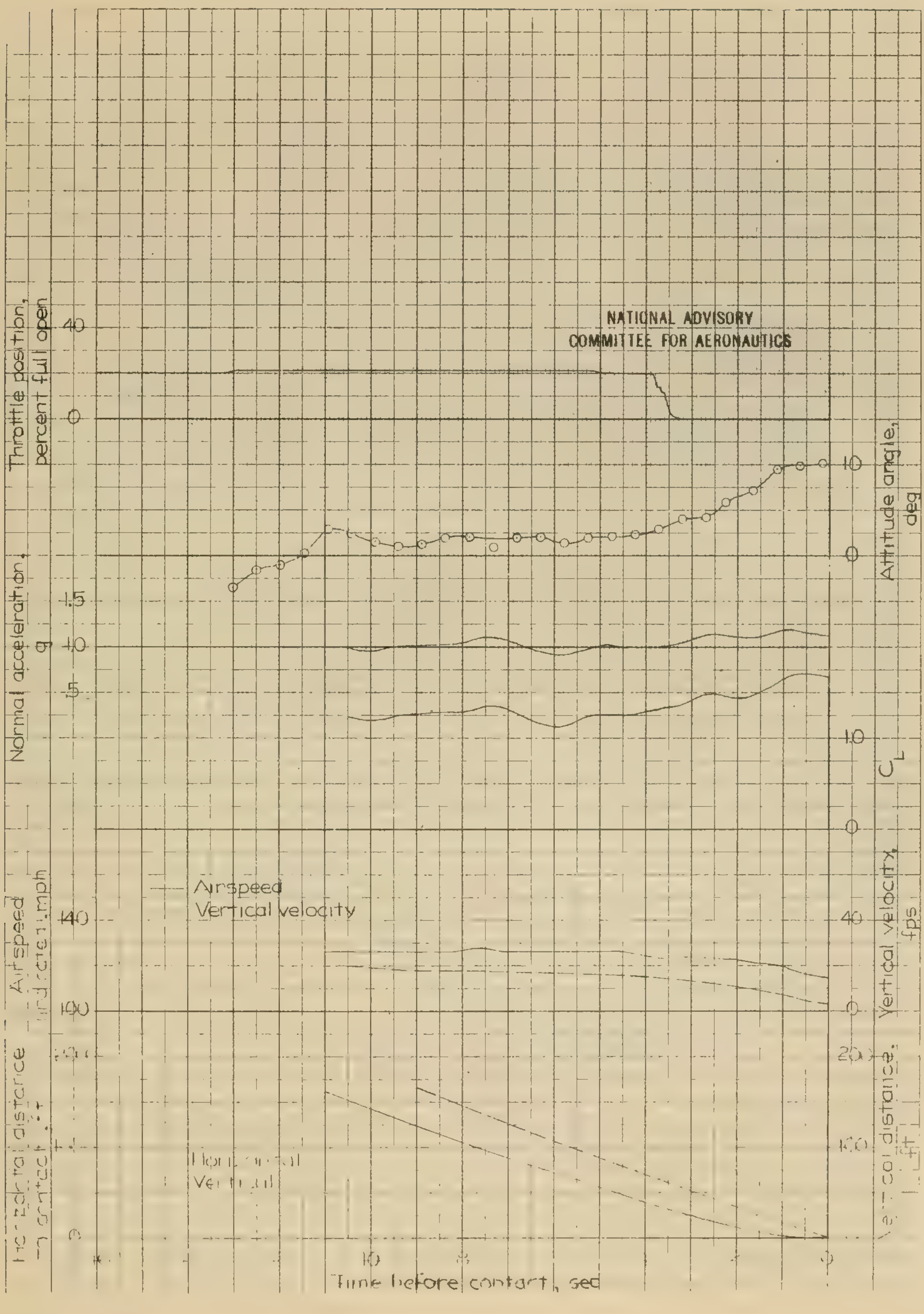


Fig. 7.- Time history of landing approach and flare. [illegible]-24 airplane; landing 11, 1942 series.

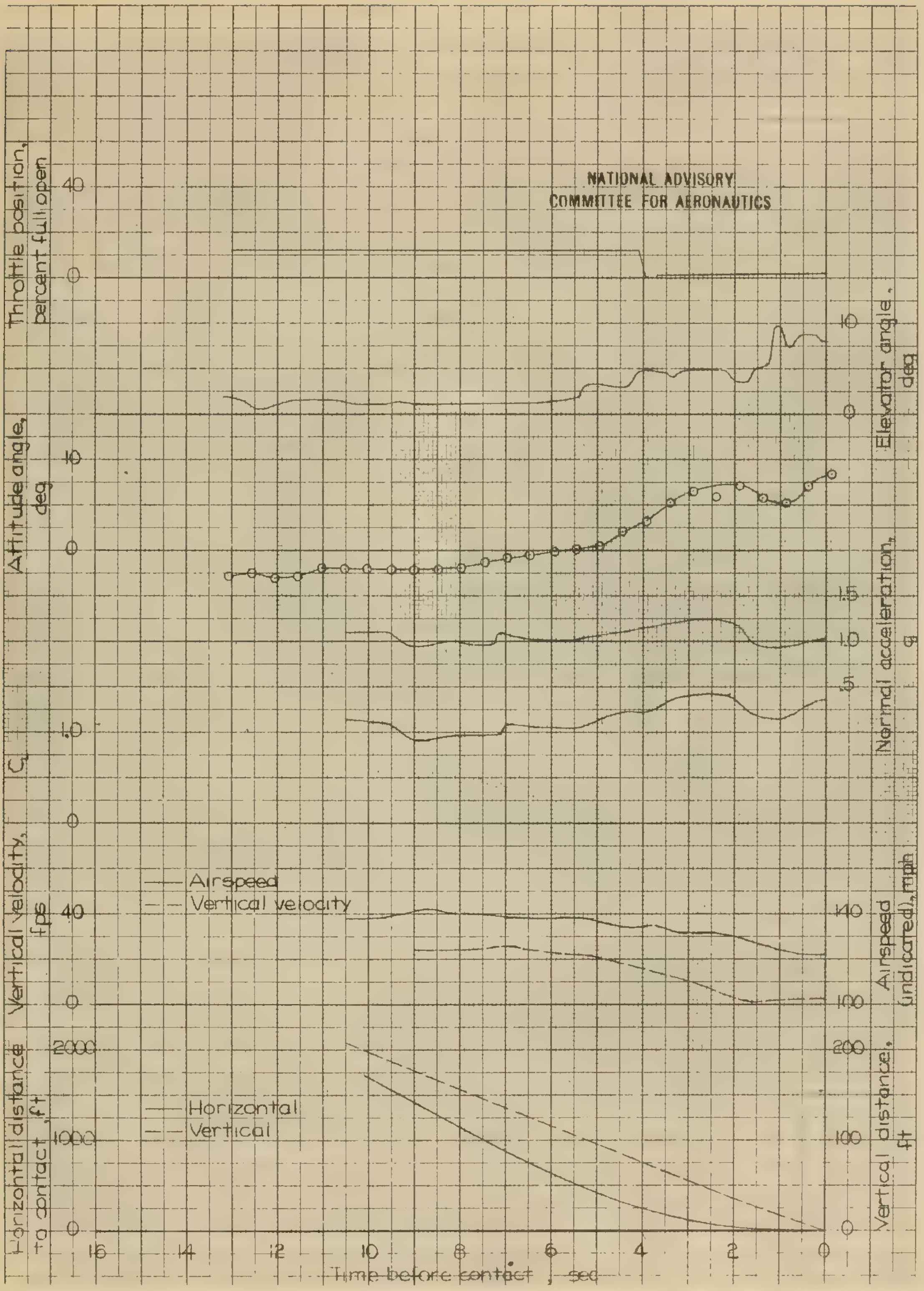


Figure 8.- Time history of landing approach and flare. B-26 airplane; landing 12, 1942 series.

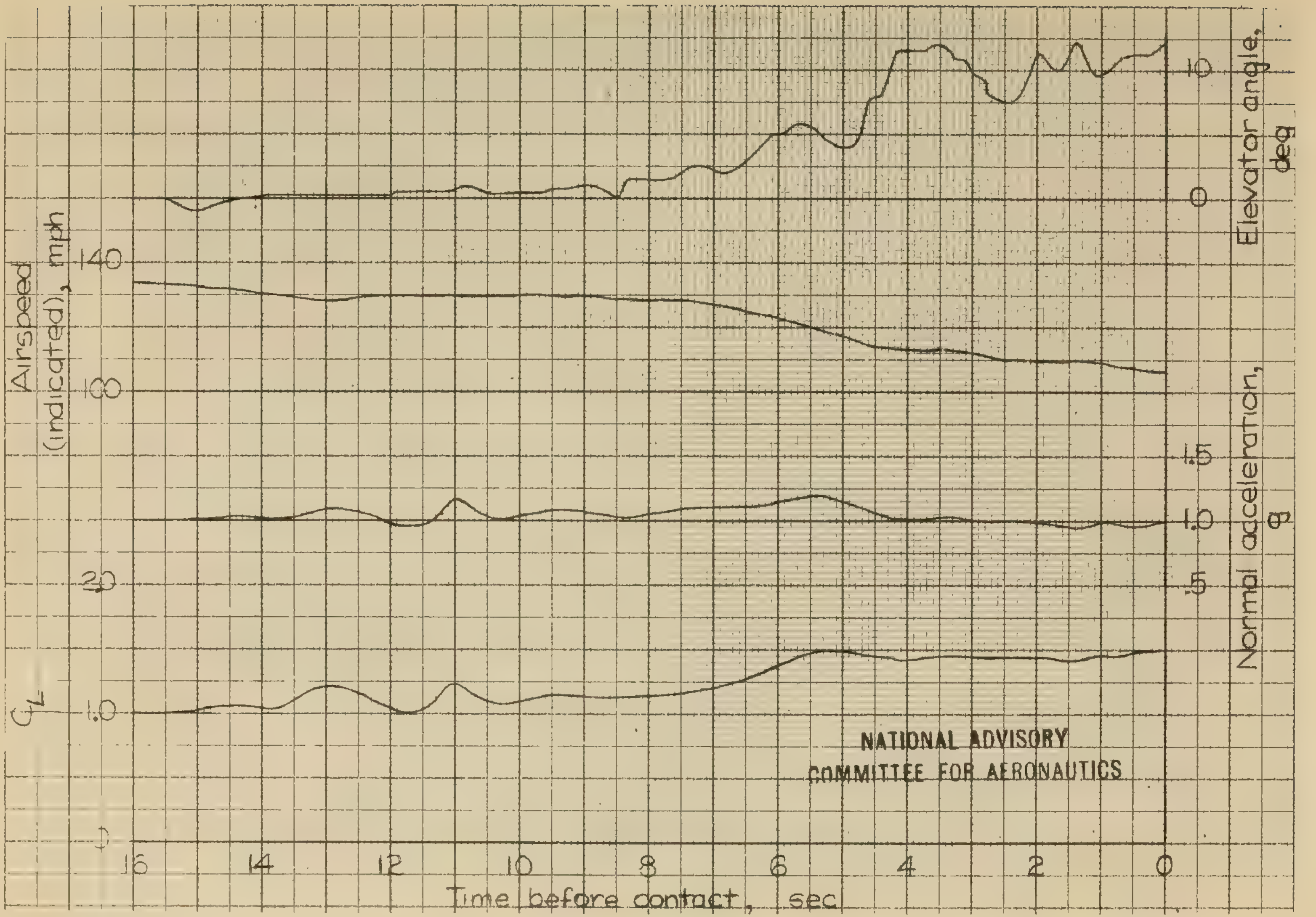


Figure 10.- Time history of landing approach and flare. B-26 airplane; landing 6, 1941 series.

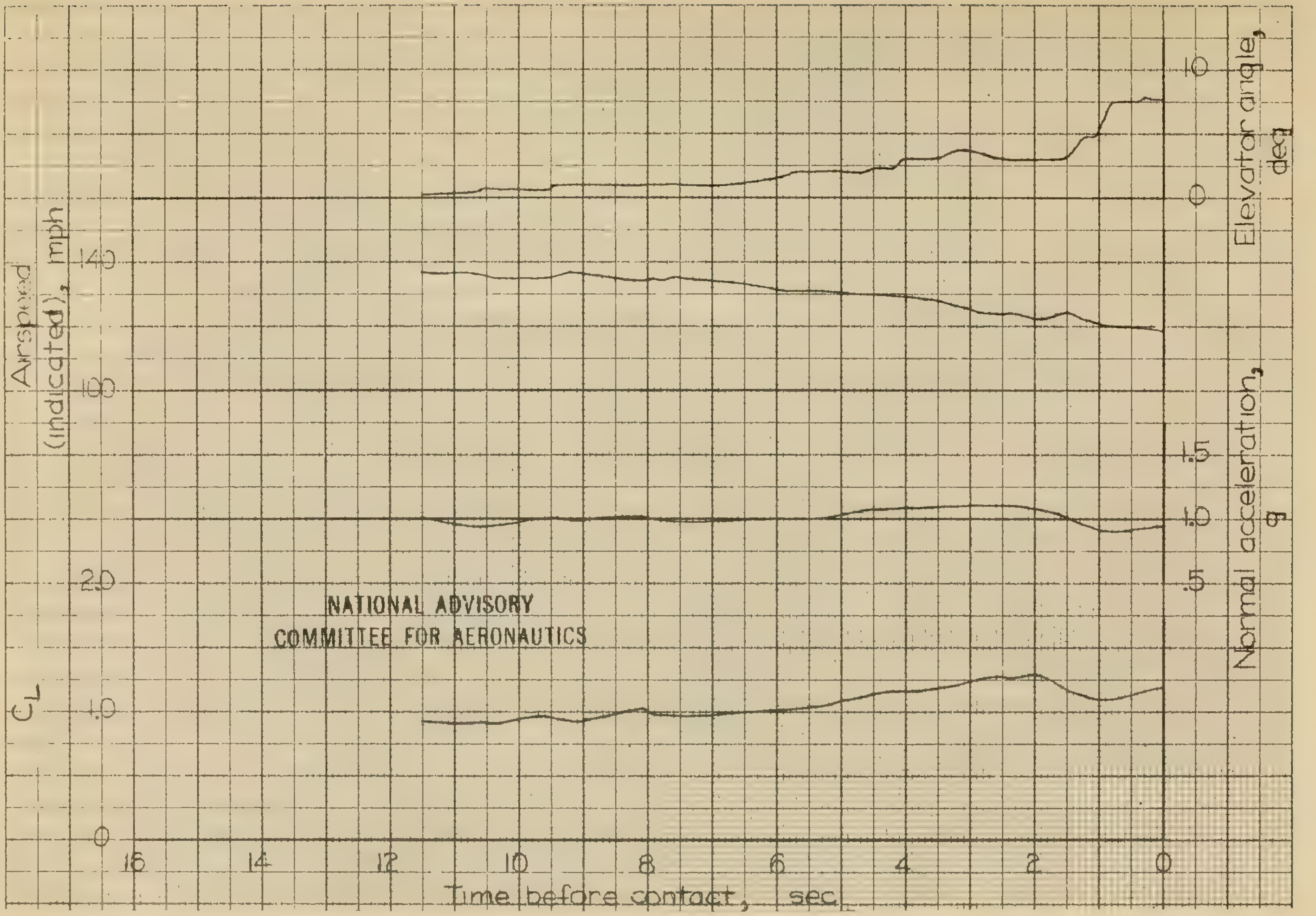


Figure 11.- Time history of landing approach and flare. B-26 airplane; landing 9, 1941 series.

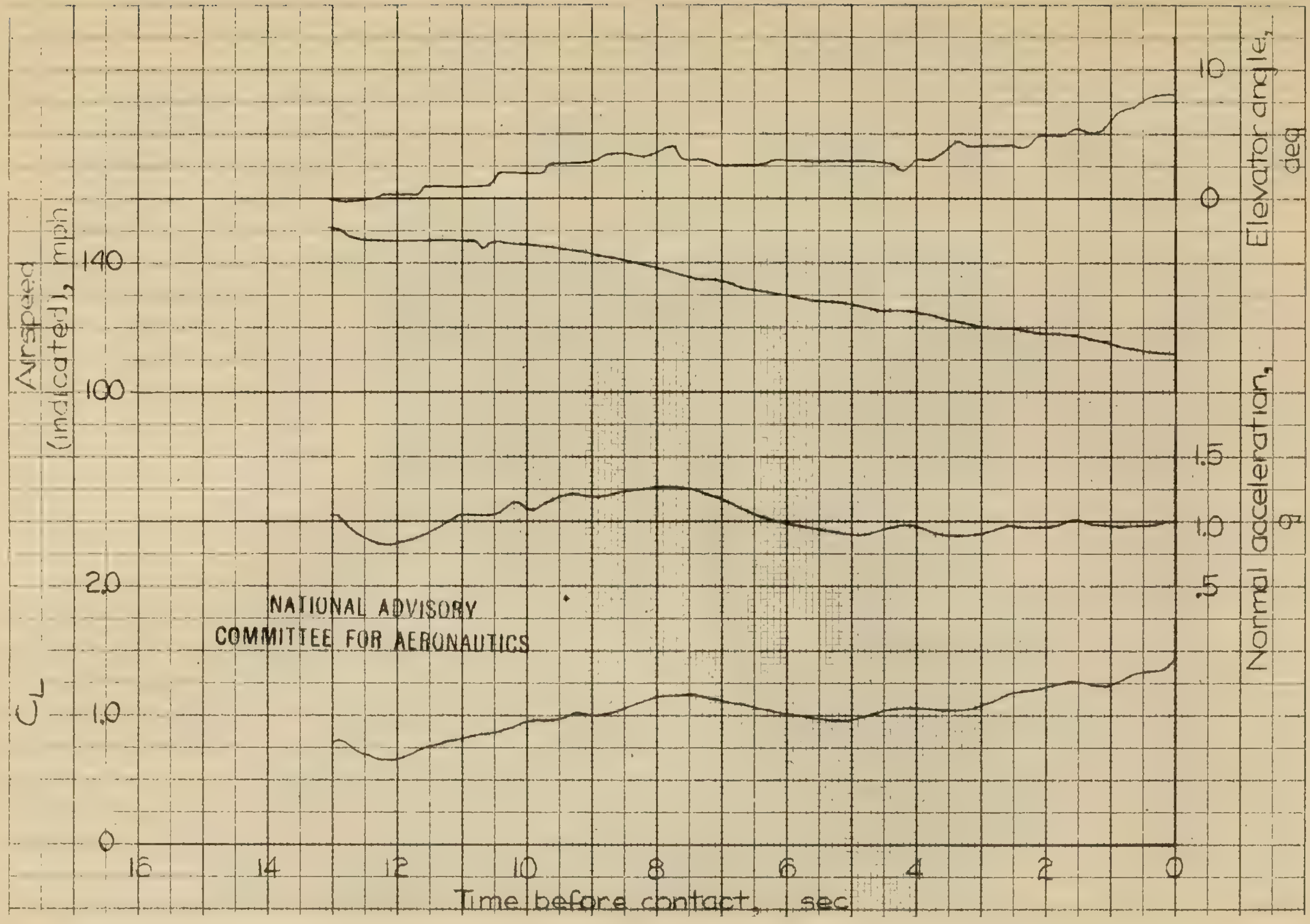


Figure 12.- Time history of landing approach and flare. B-26 airplane; landing 11, 1941 series.

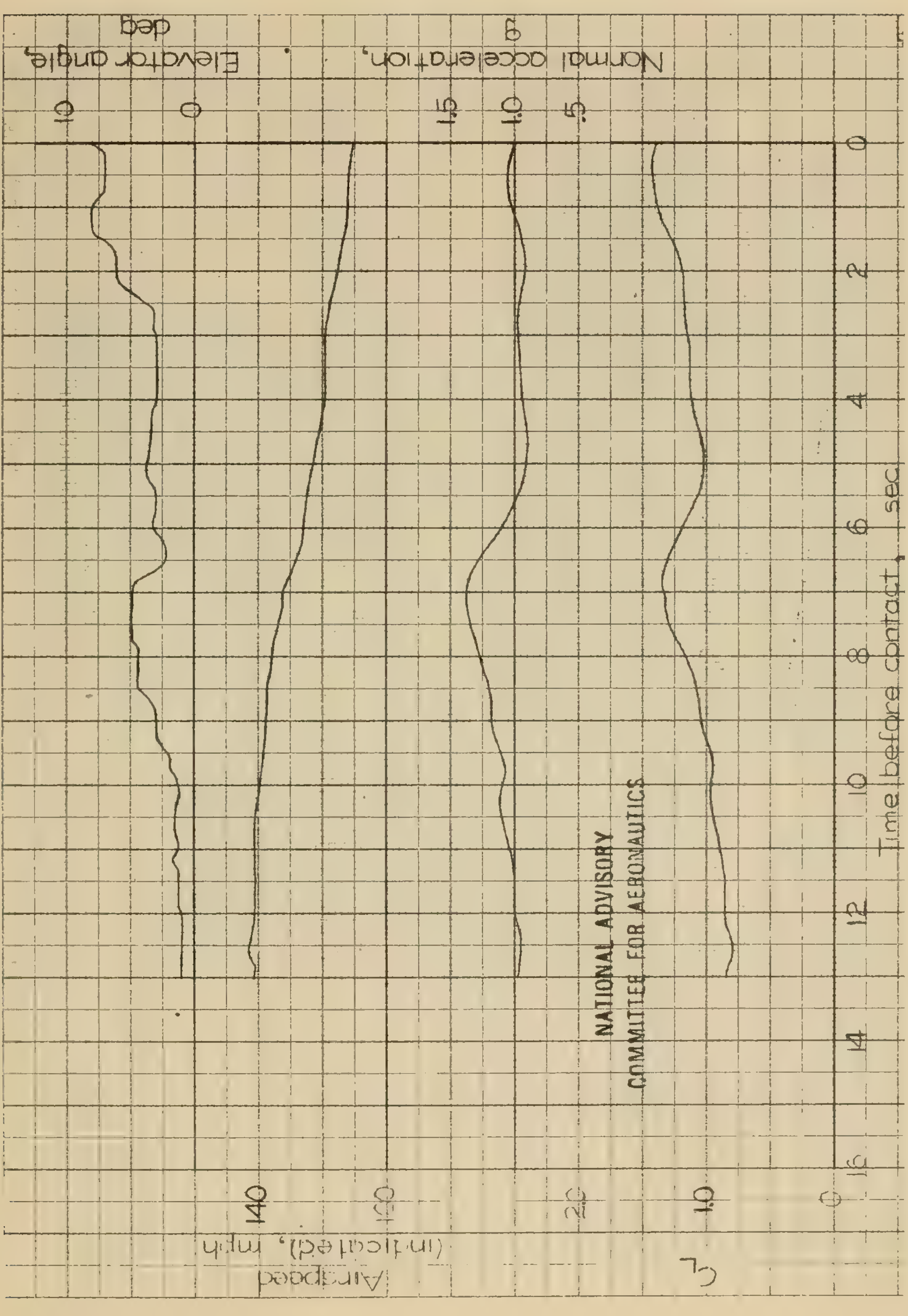


Figure 13.- Time history of landing approach and flare. B-26 airplane; landing 12, 1941 series.

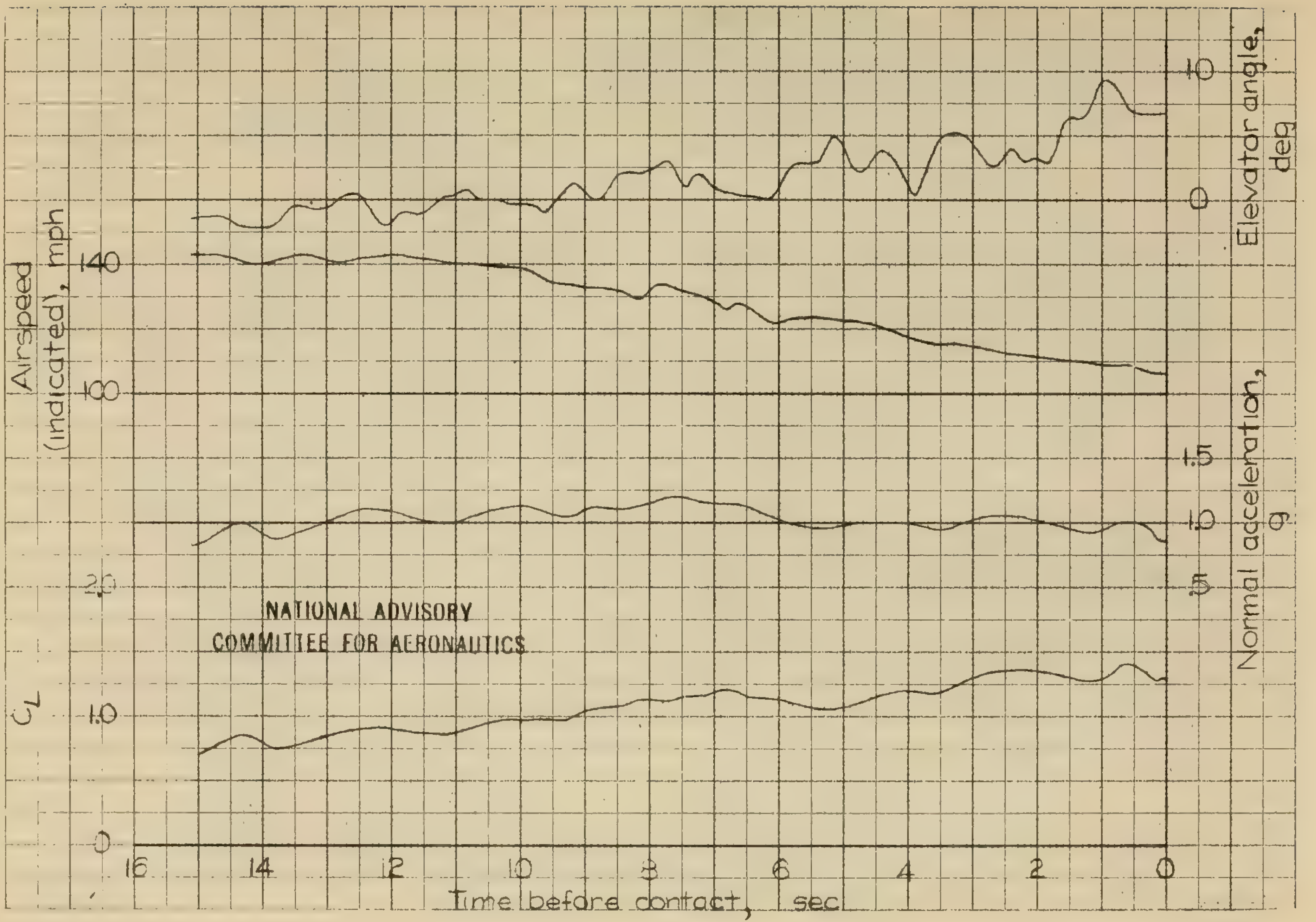


Figure 14.- Time history of landing approach and flare. B-26 airplane; landing 14, 1941 series.

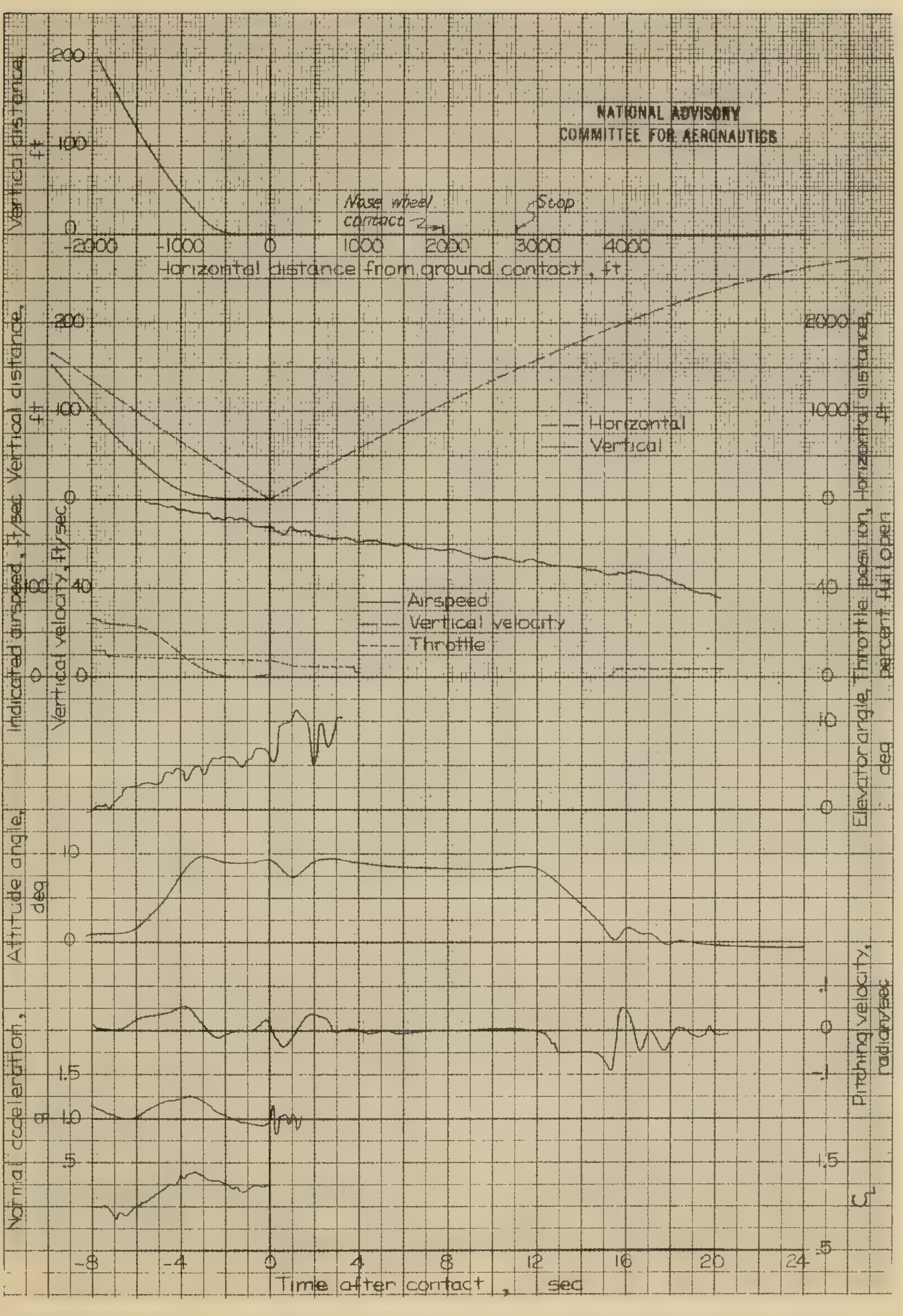


Figure 15.- Flight path and time history of landing run. B-26 airplane; landing 8, 1941 series.

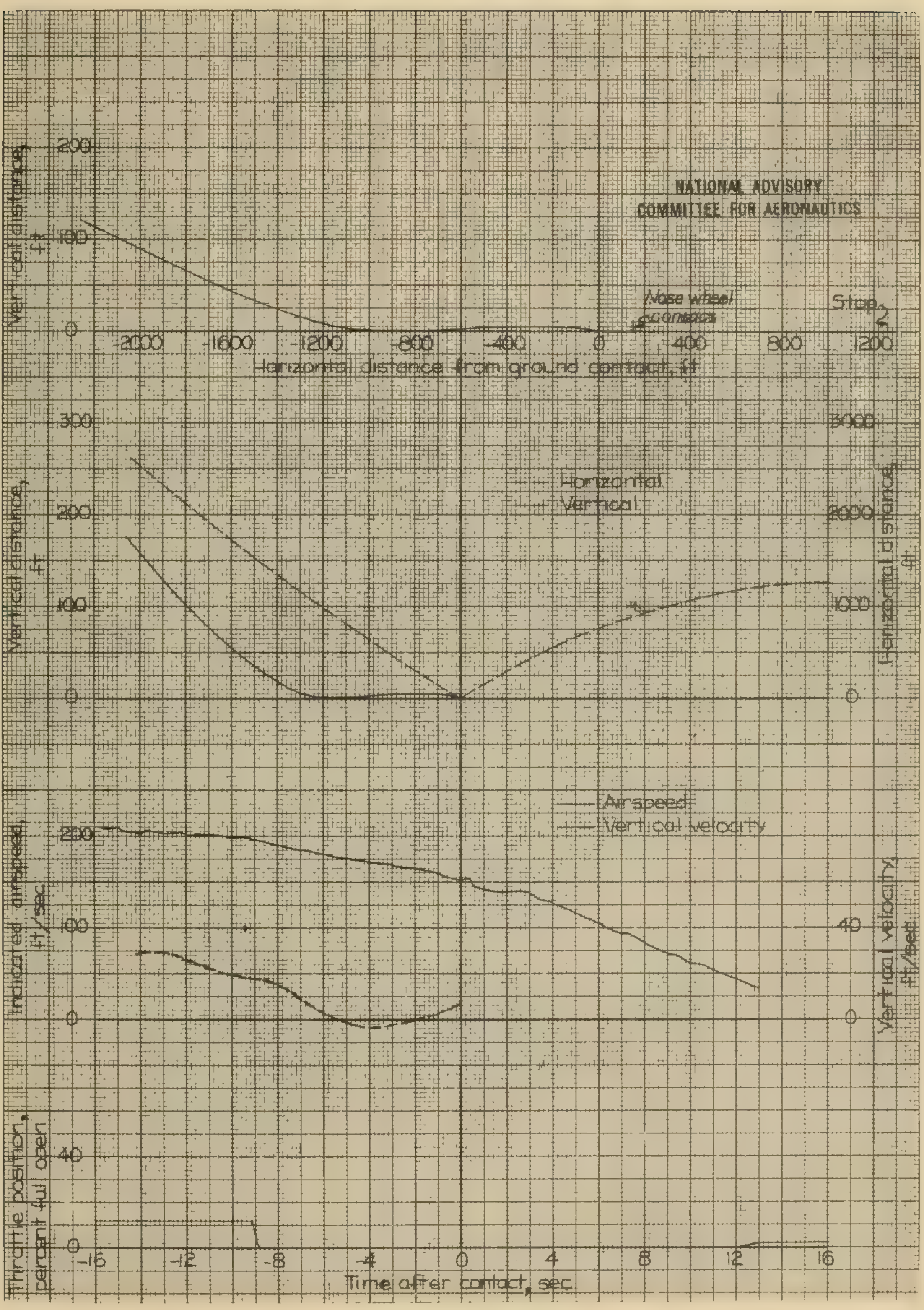
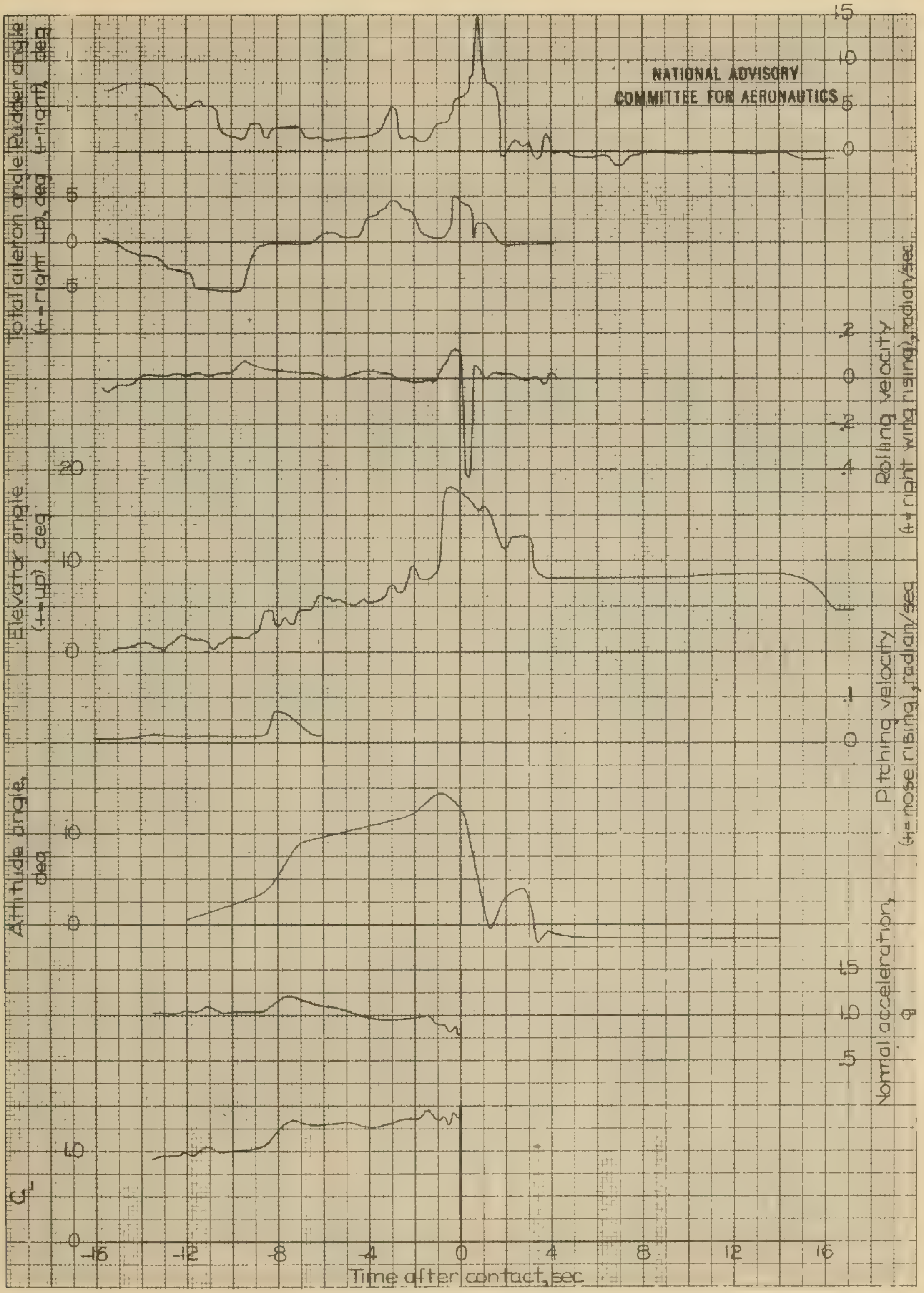


Figure 16.- Flight path and time history of landing run. B-26 airplane; landing 10, 1941 series.



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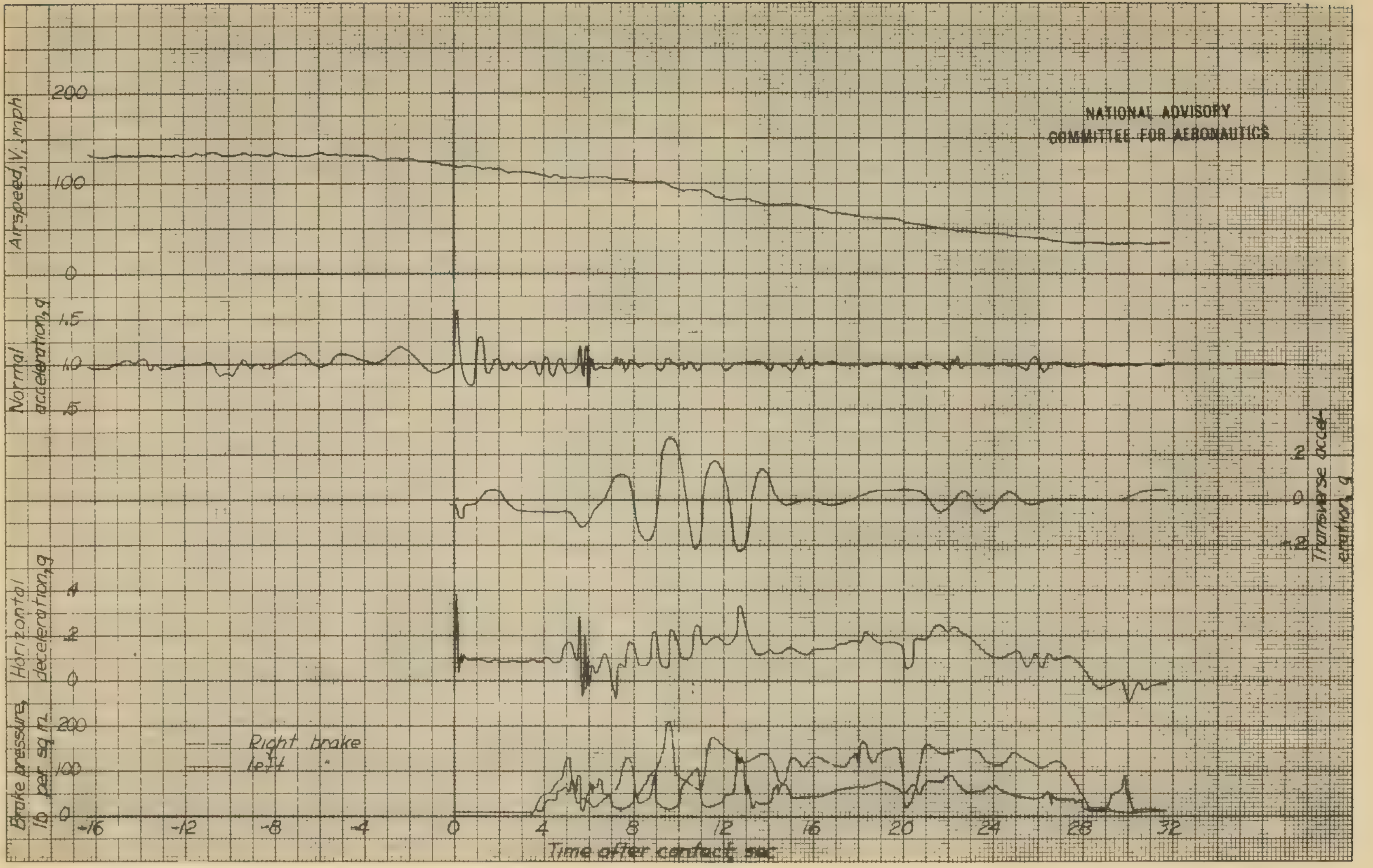
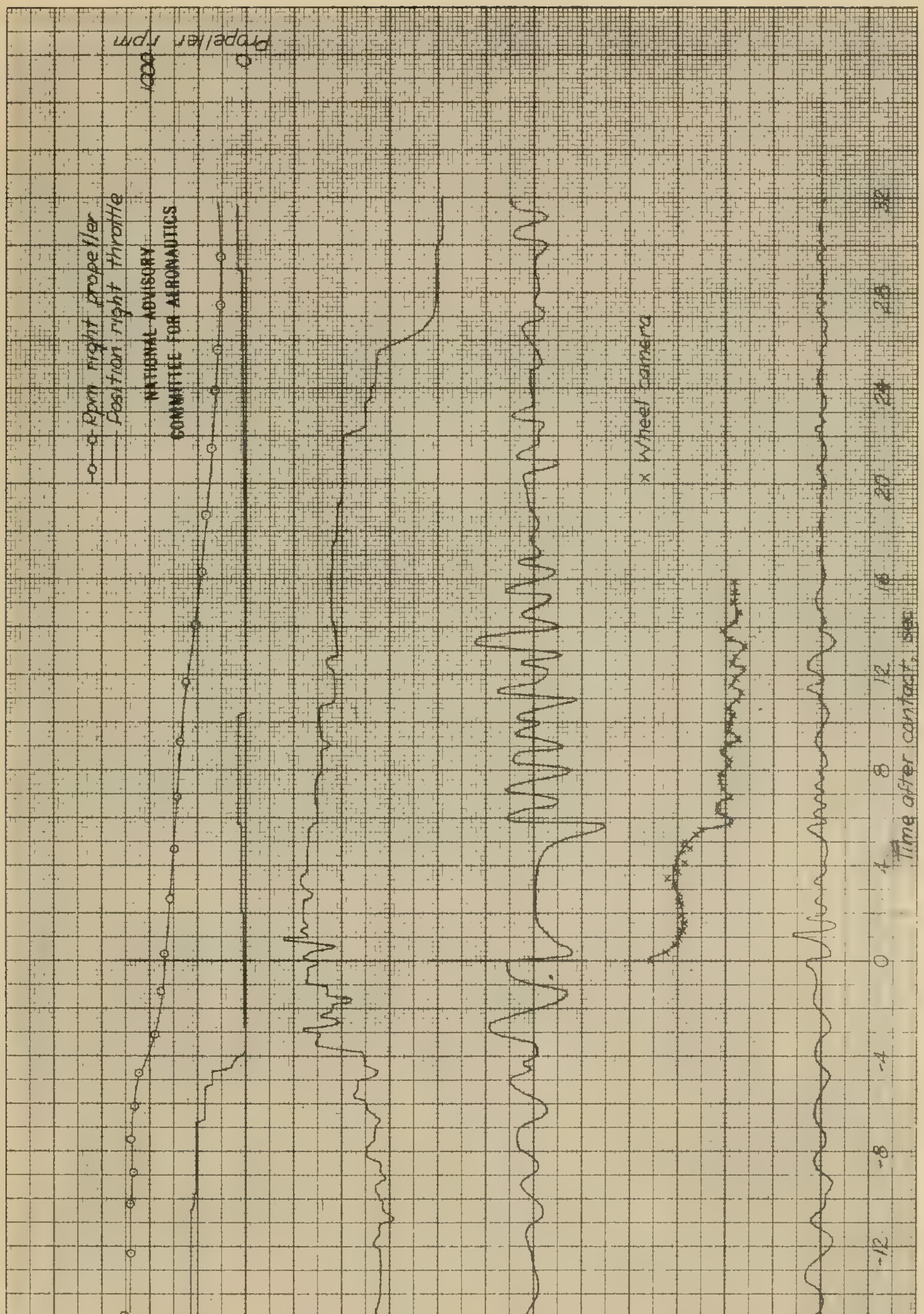


Figure 17.- Time history of landing run. B-26 airplane; landing 1, 1942 series.



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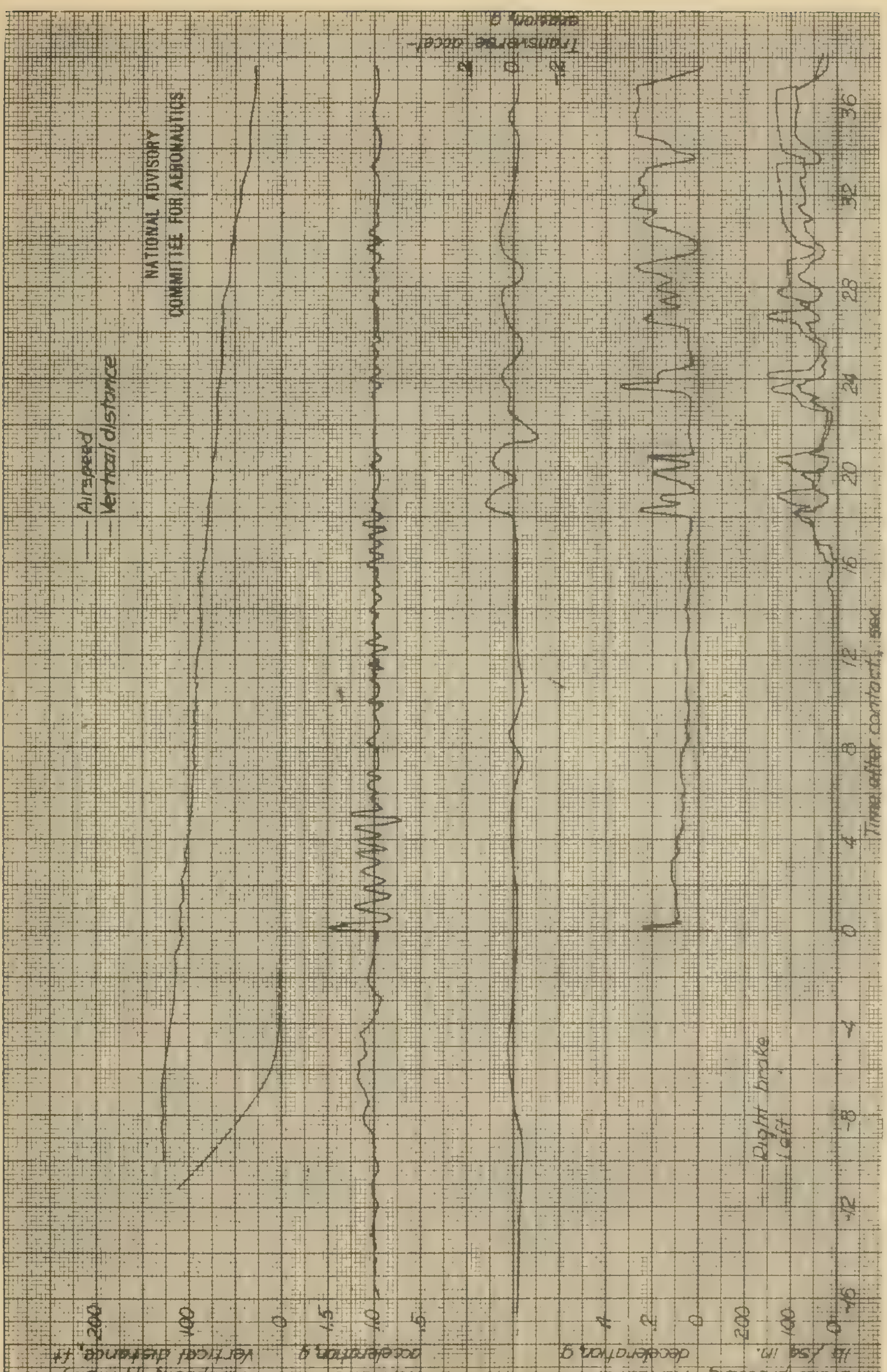
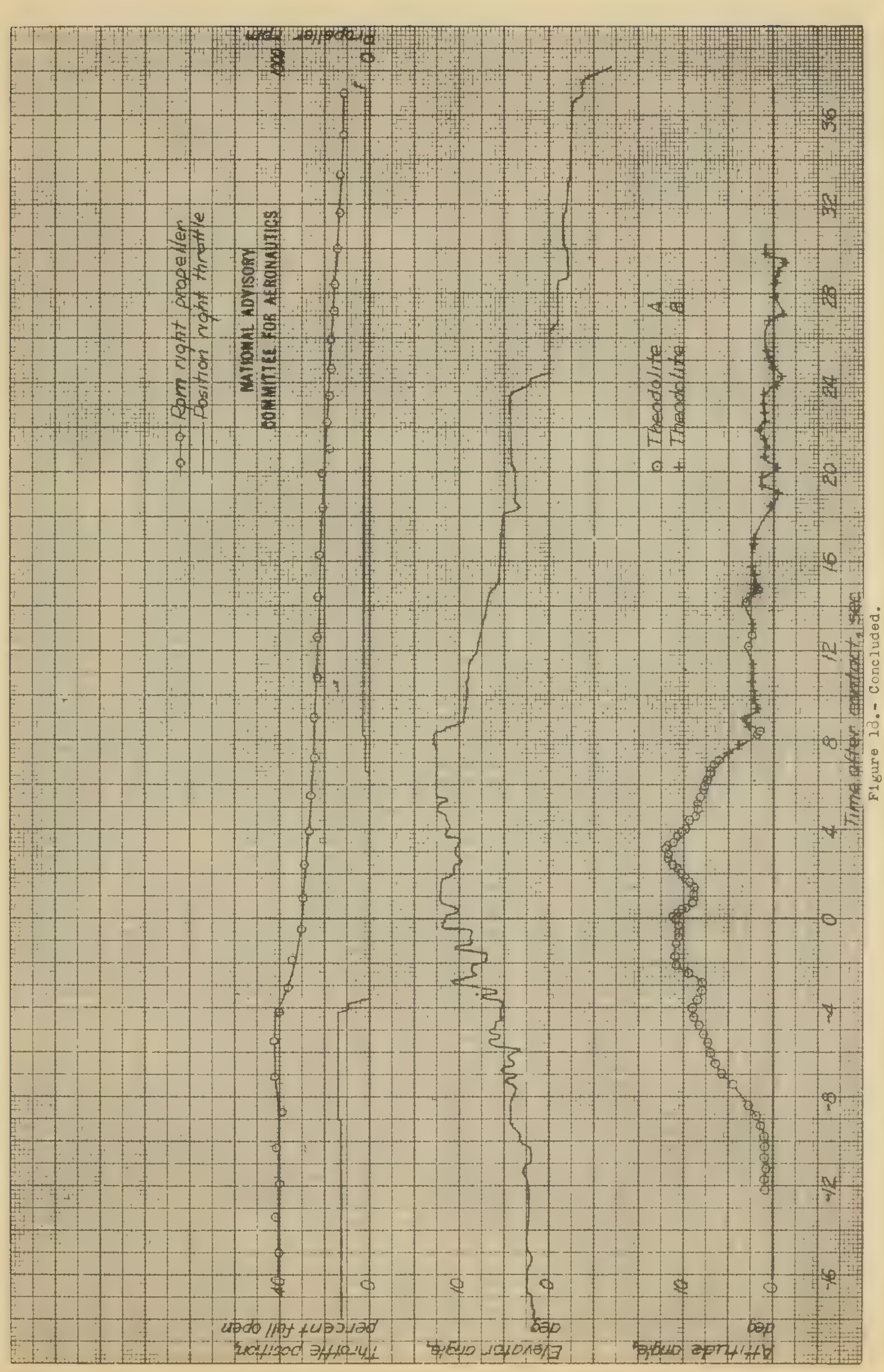


Figure 18.- Time history of landing run. B-26 airplane; landing 4, 1942 series.



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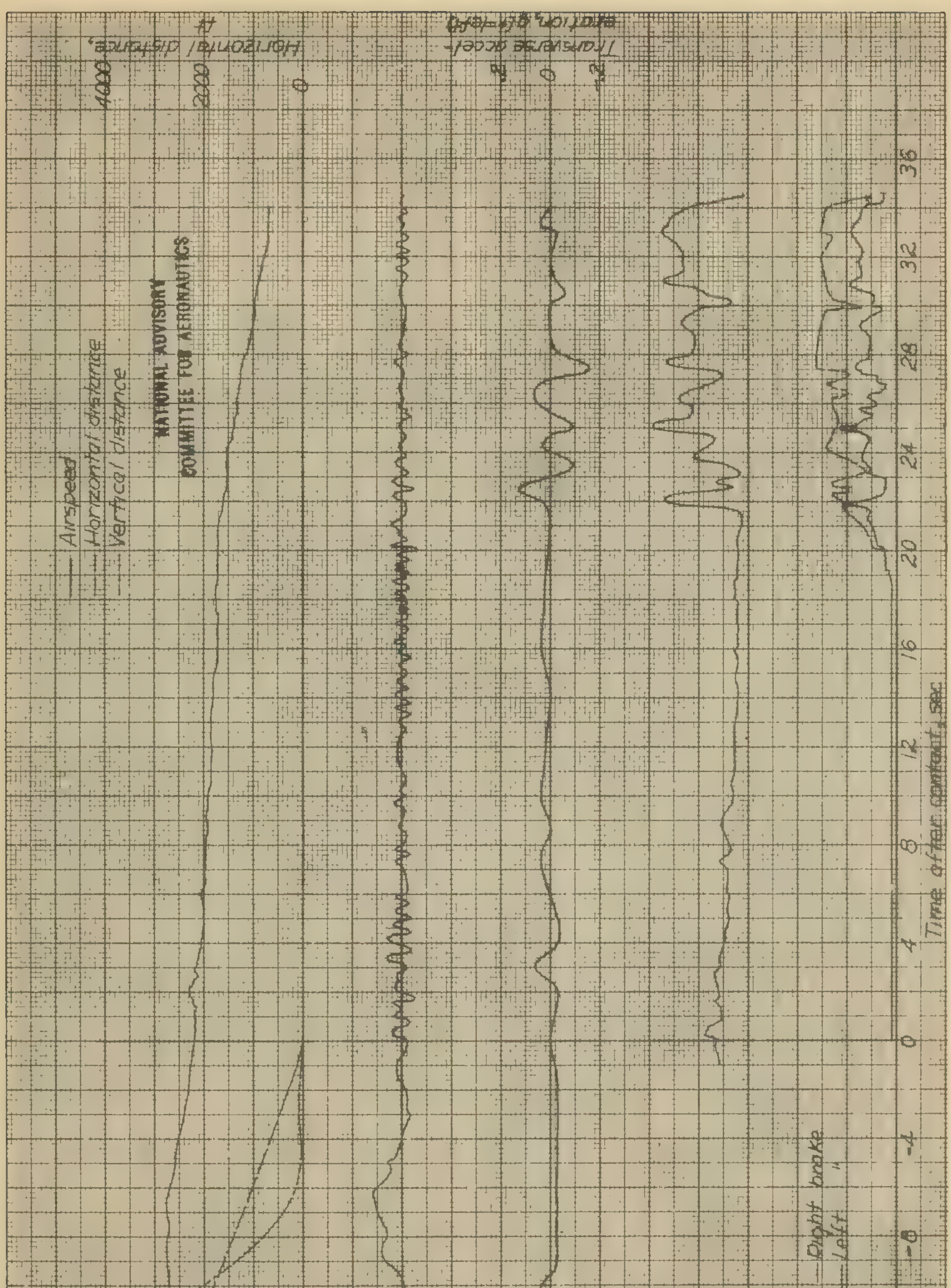
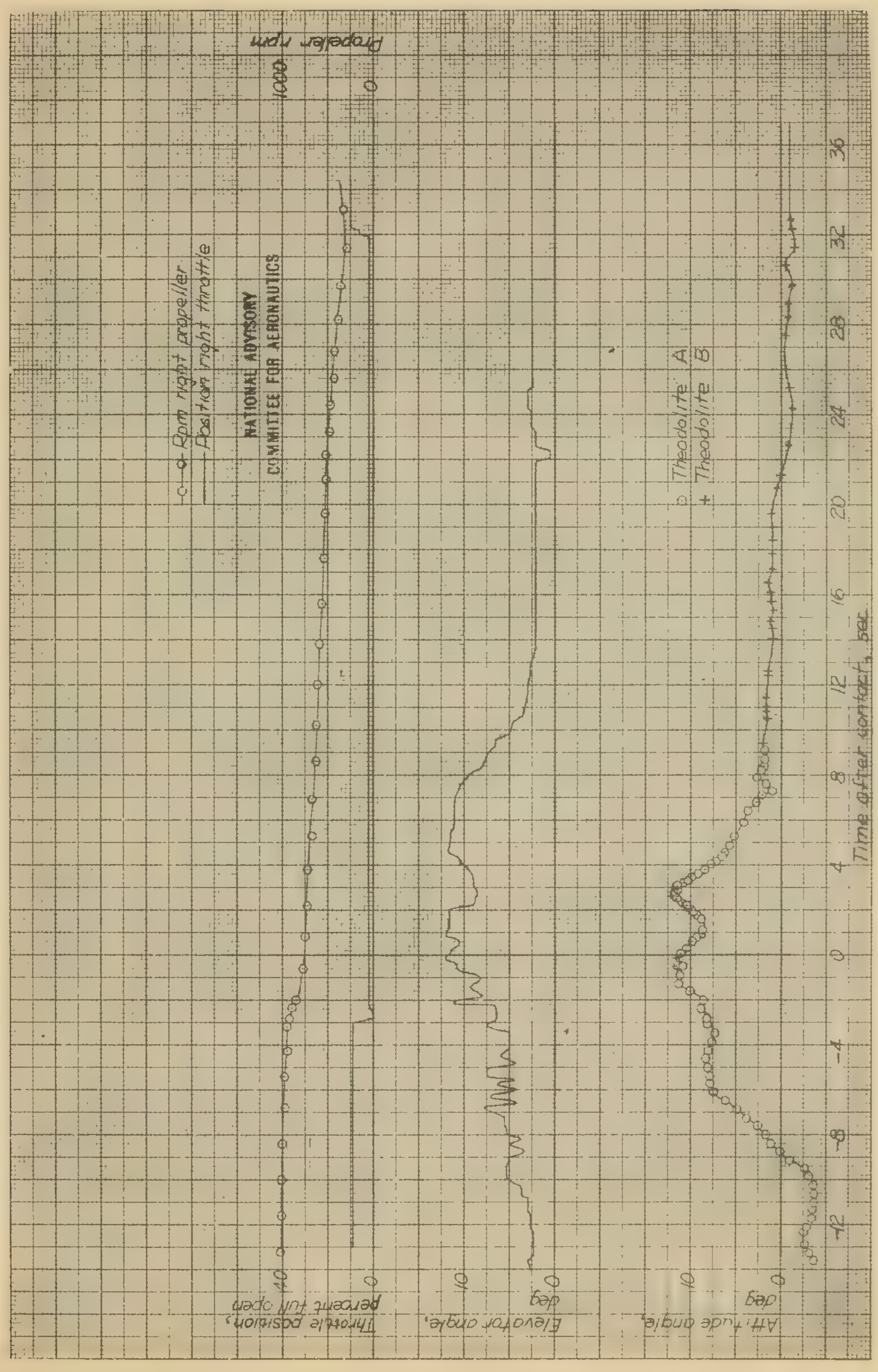


Figure 19.- Time history of landing run. B-26 airplane; landing 5, 1942 series.



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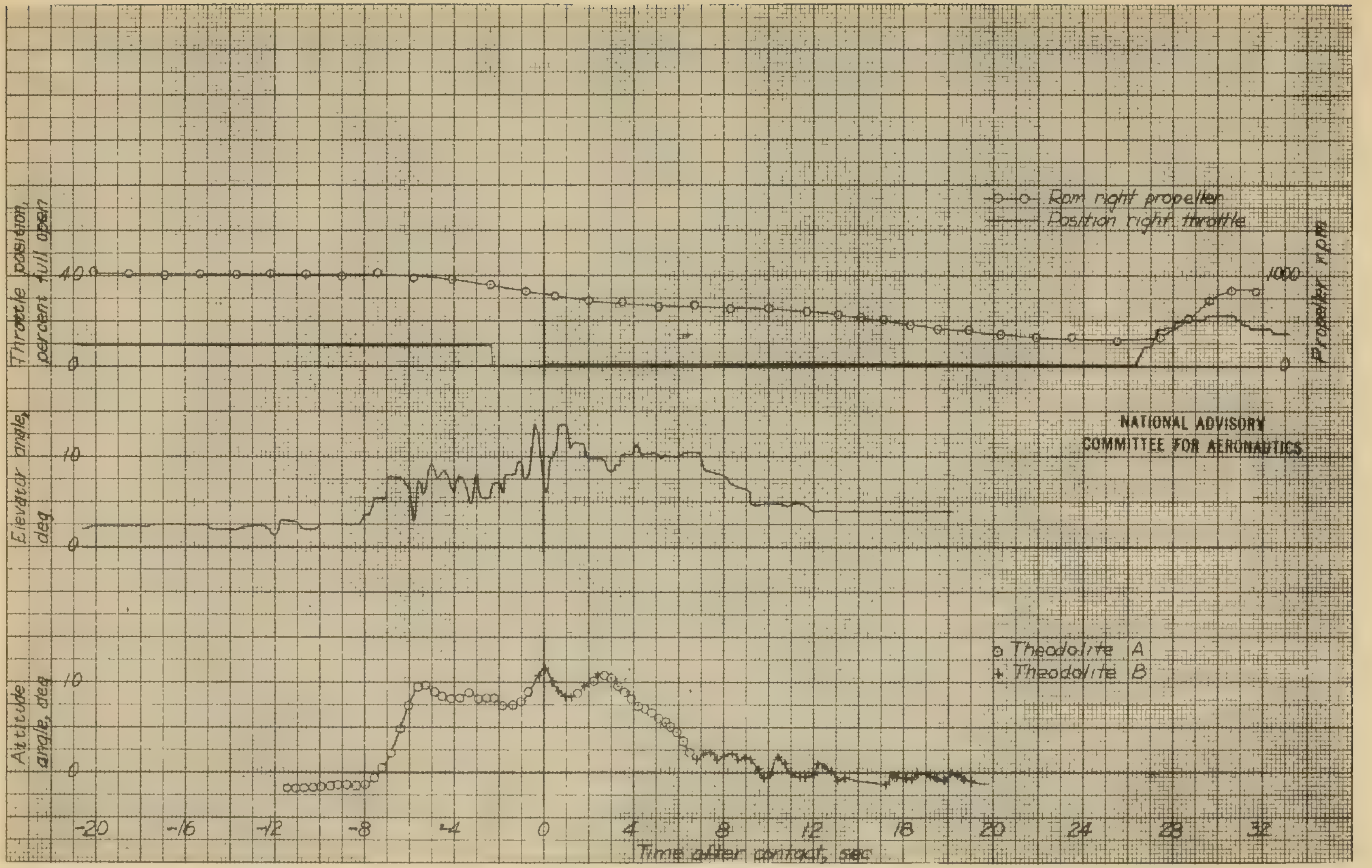

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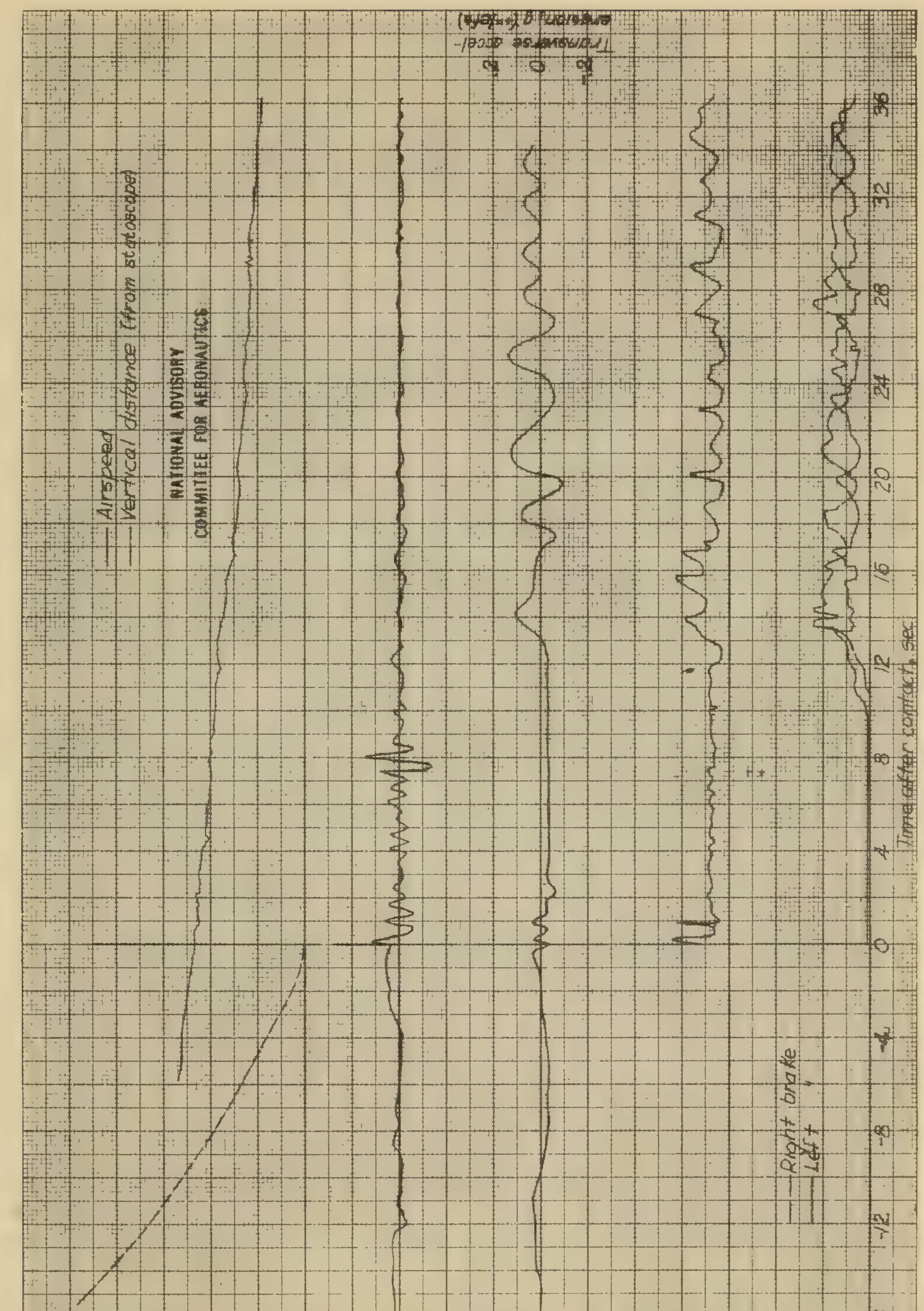
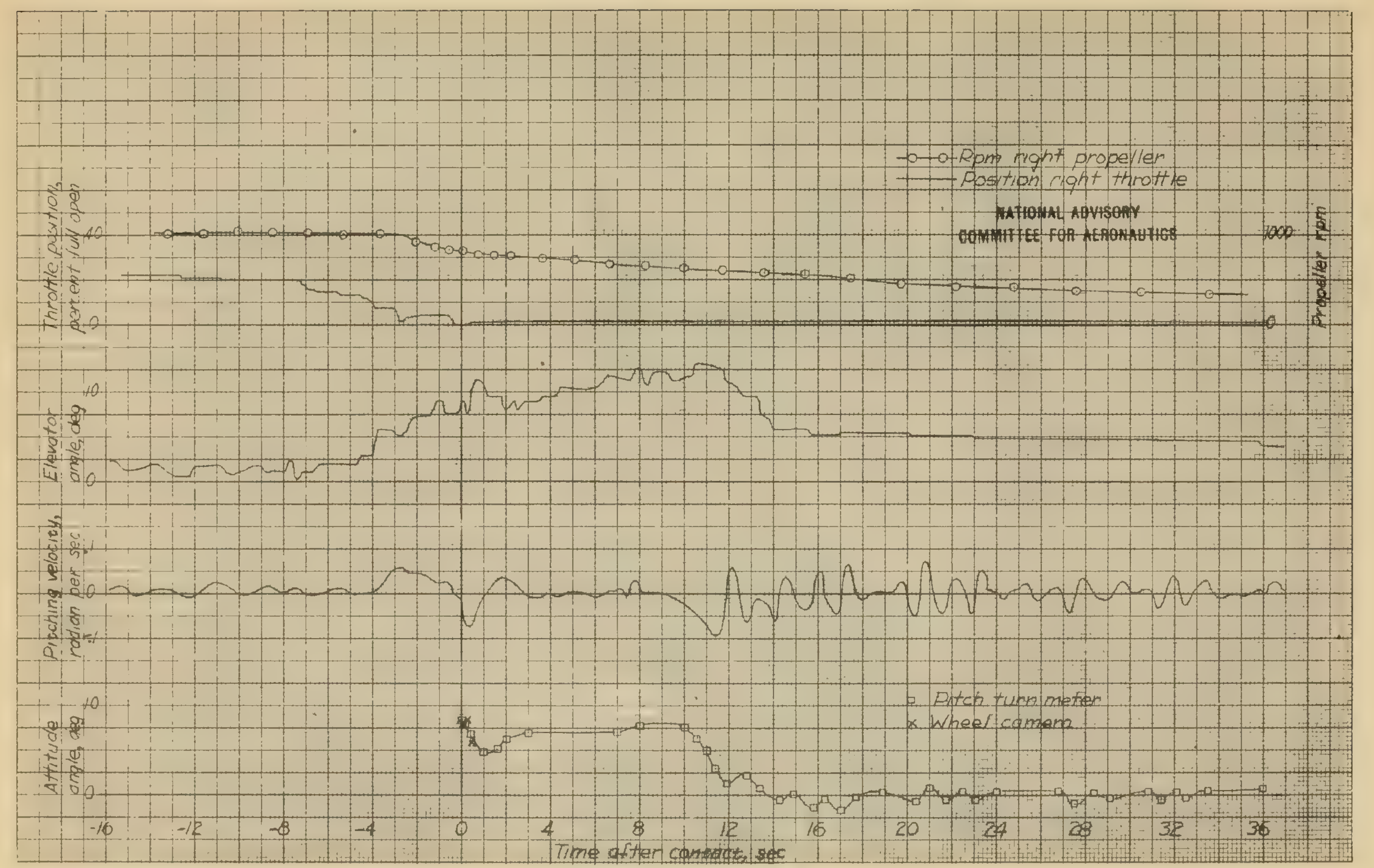


Figure 21.- Time history of landing run. B-26 airplane; landing 10, 1942 series.
(Landing made just after a heavy rain.)



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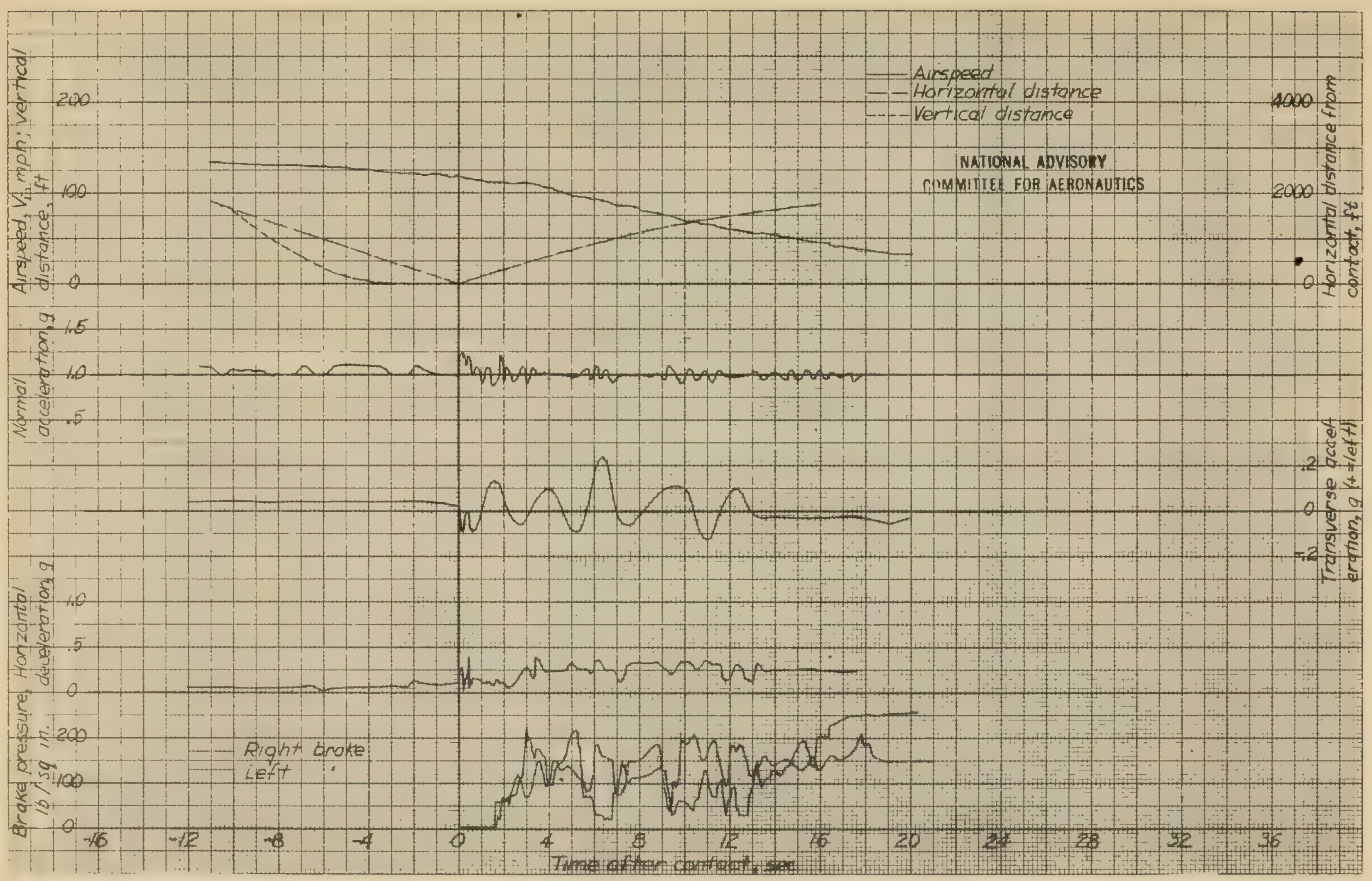
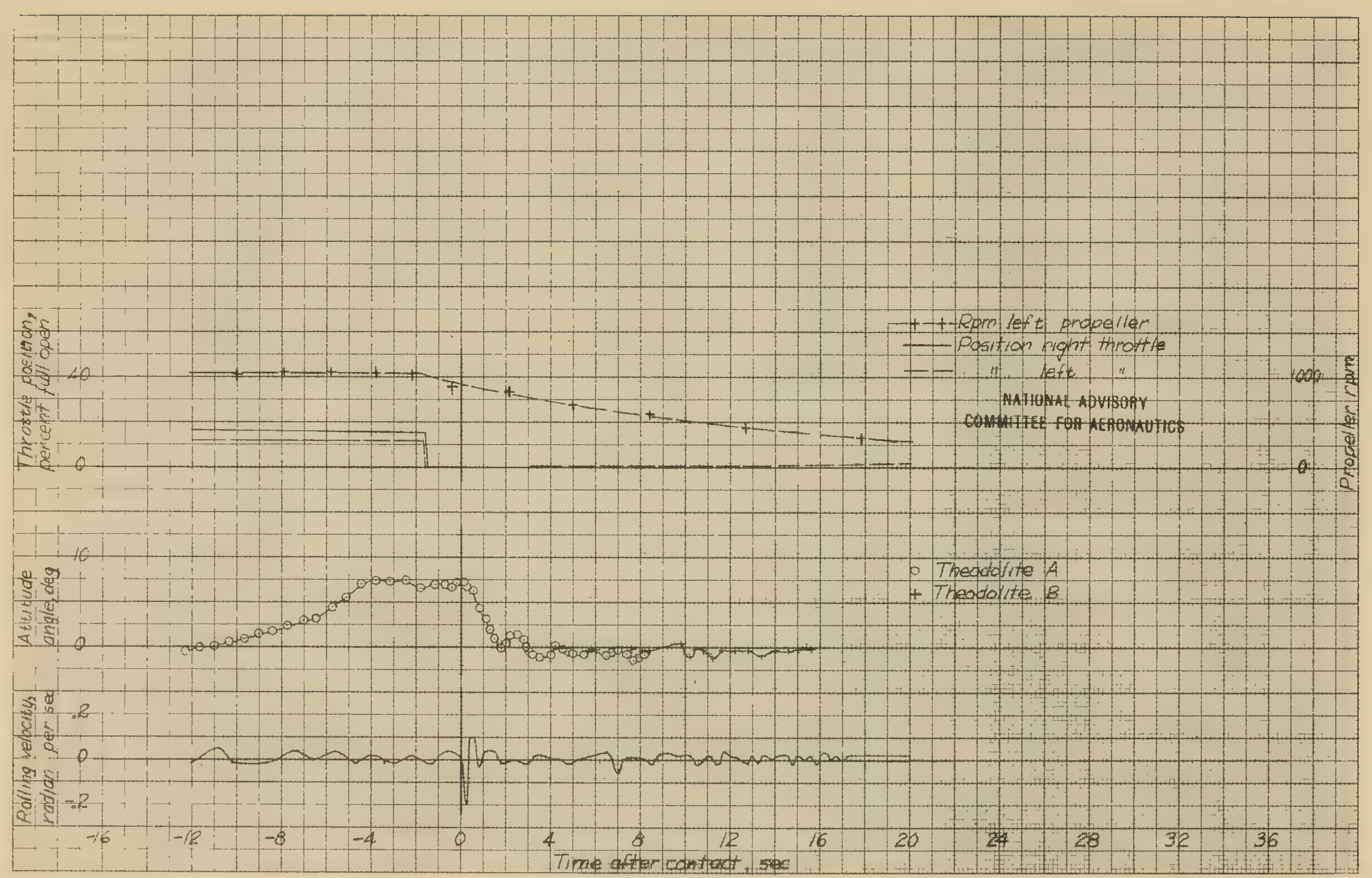


Figure 22.- Time history of landing run. B-26 airplane; landing 14, 1942 series.



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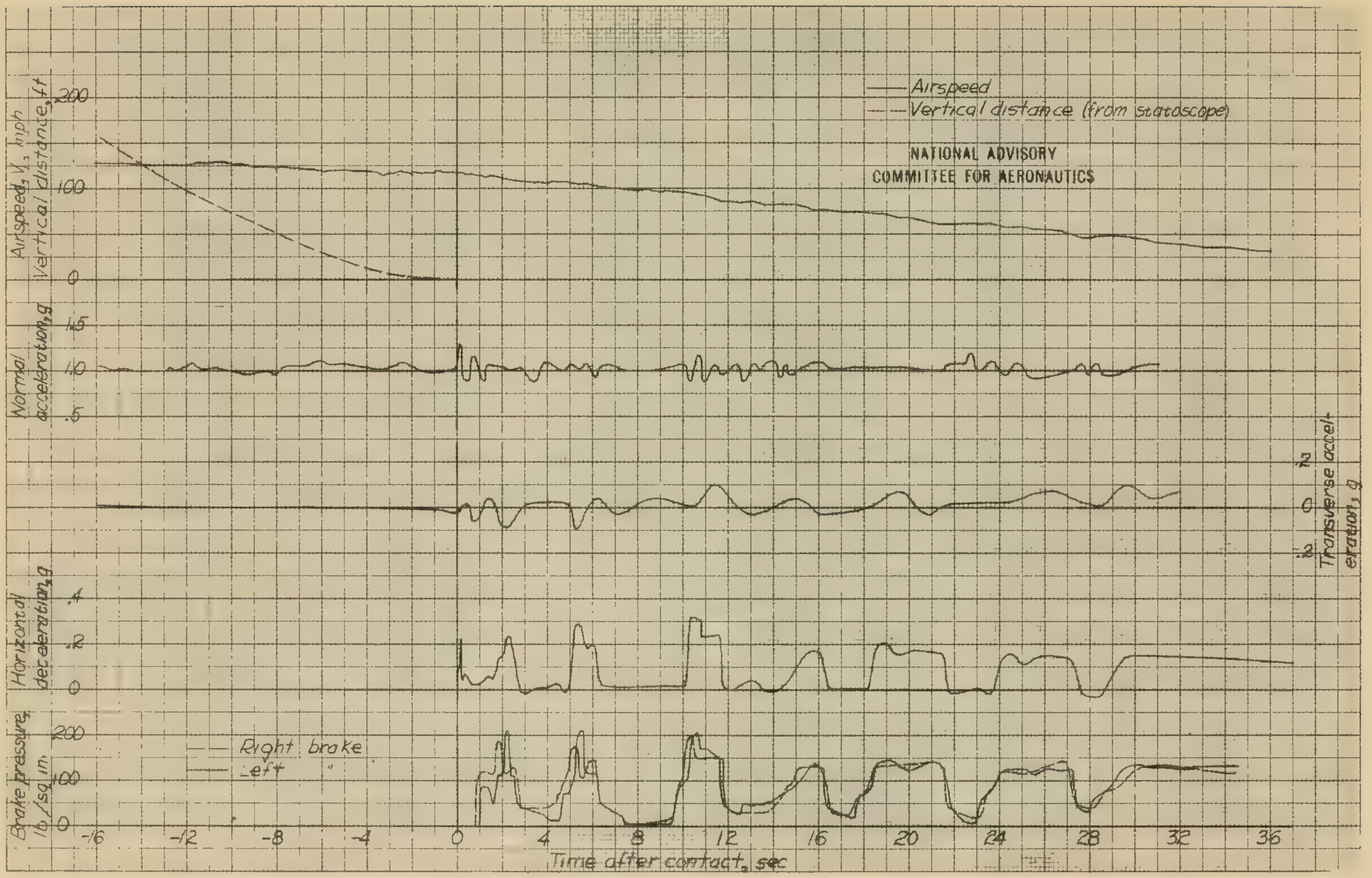
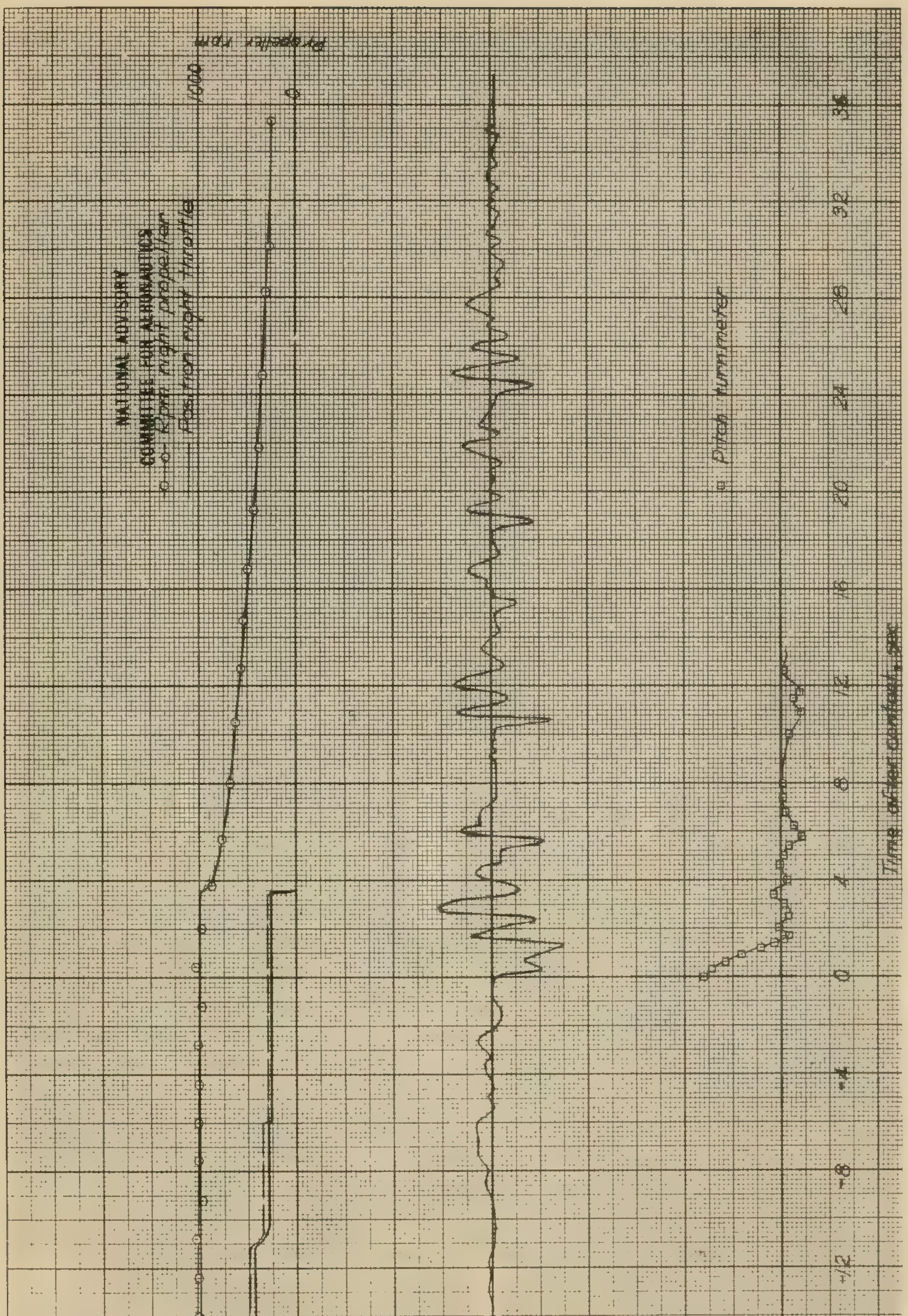


Figure 23.- Time history of landing run. B-26 airplane; landing 15, 1942 series.



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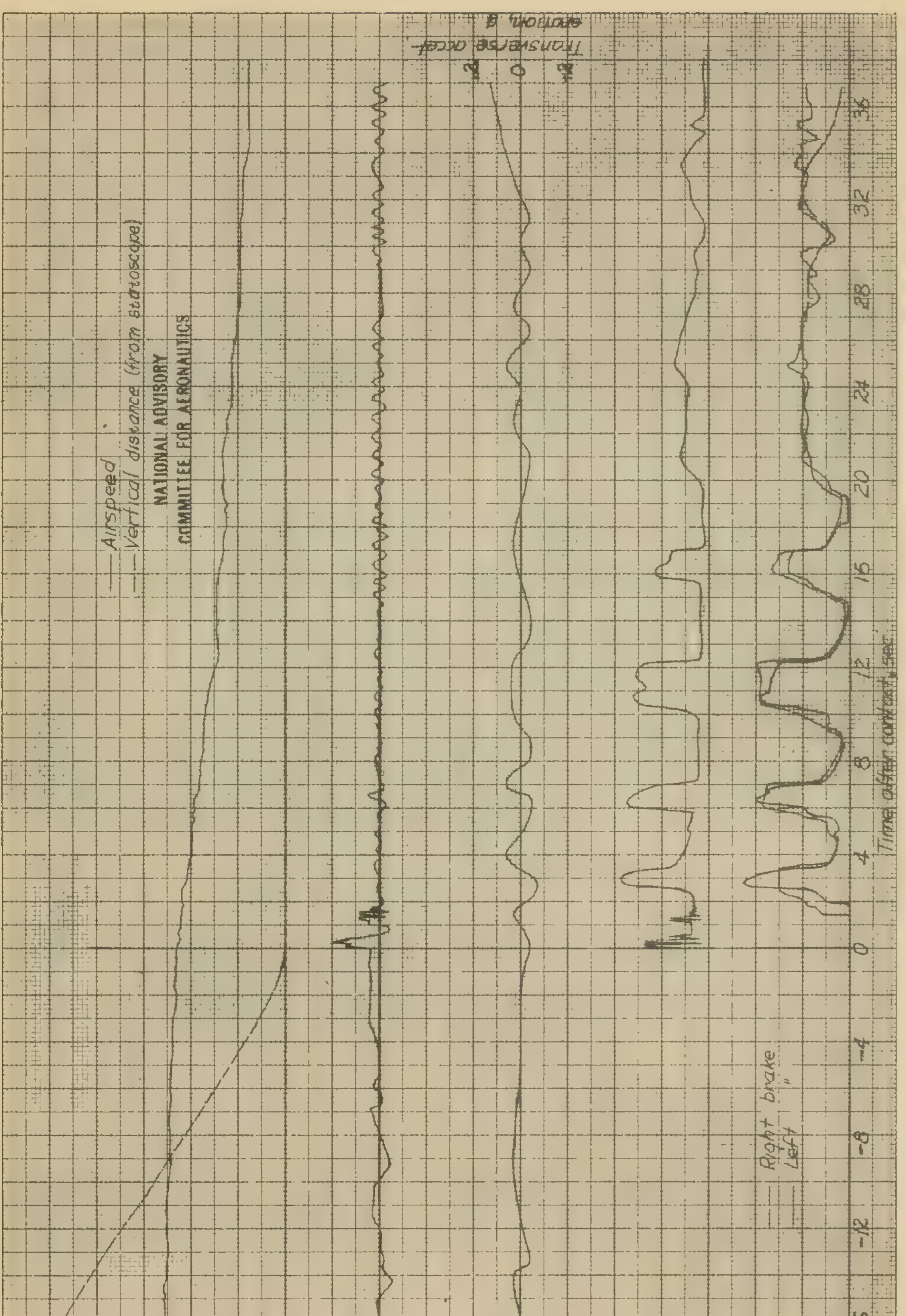
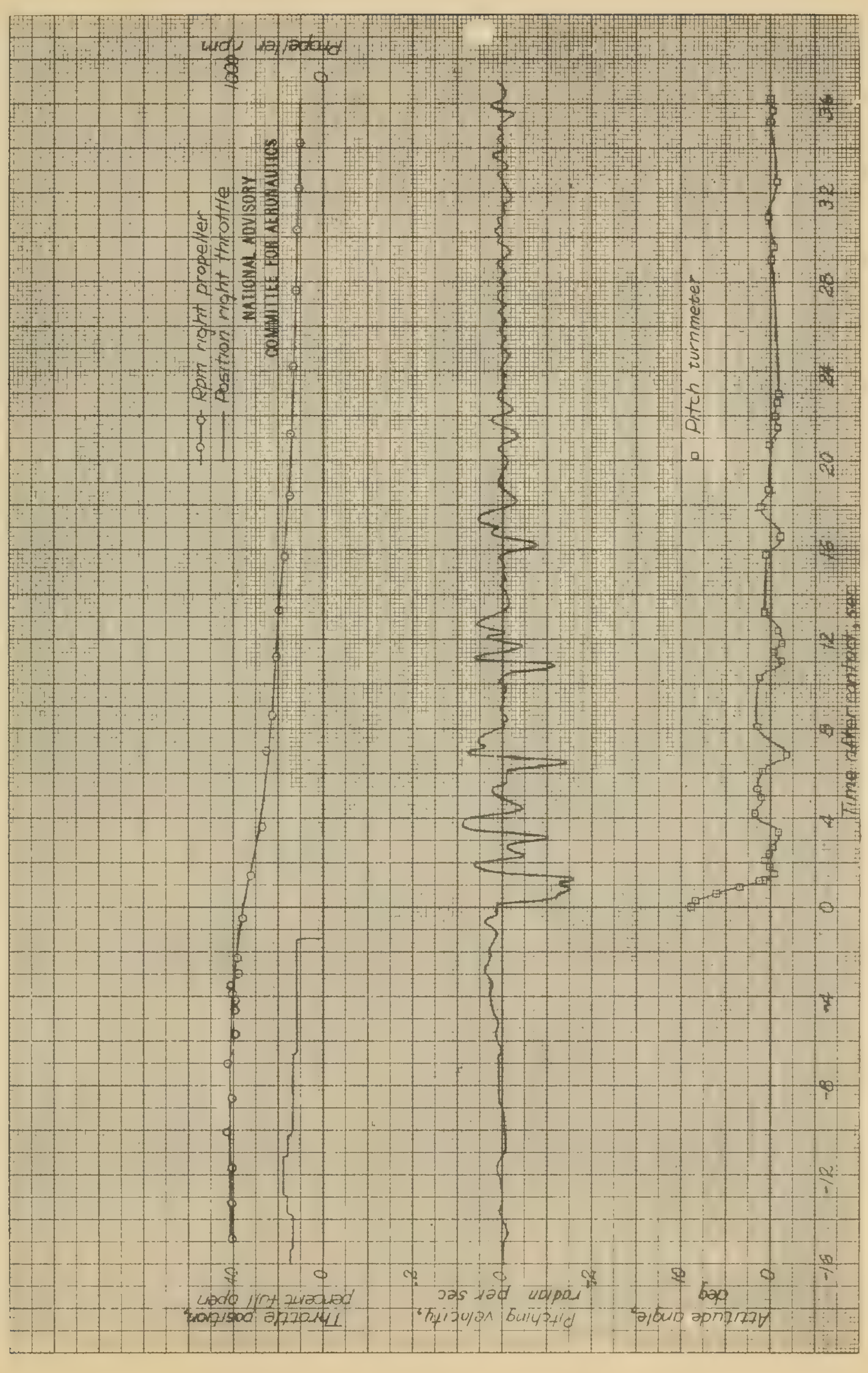


Figure 24.- Time history of landing run. B-26 airplane; landing 16, 1942 series.



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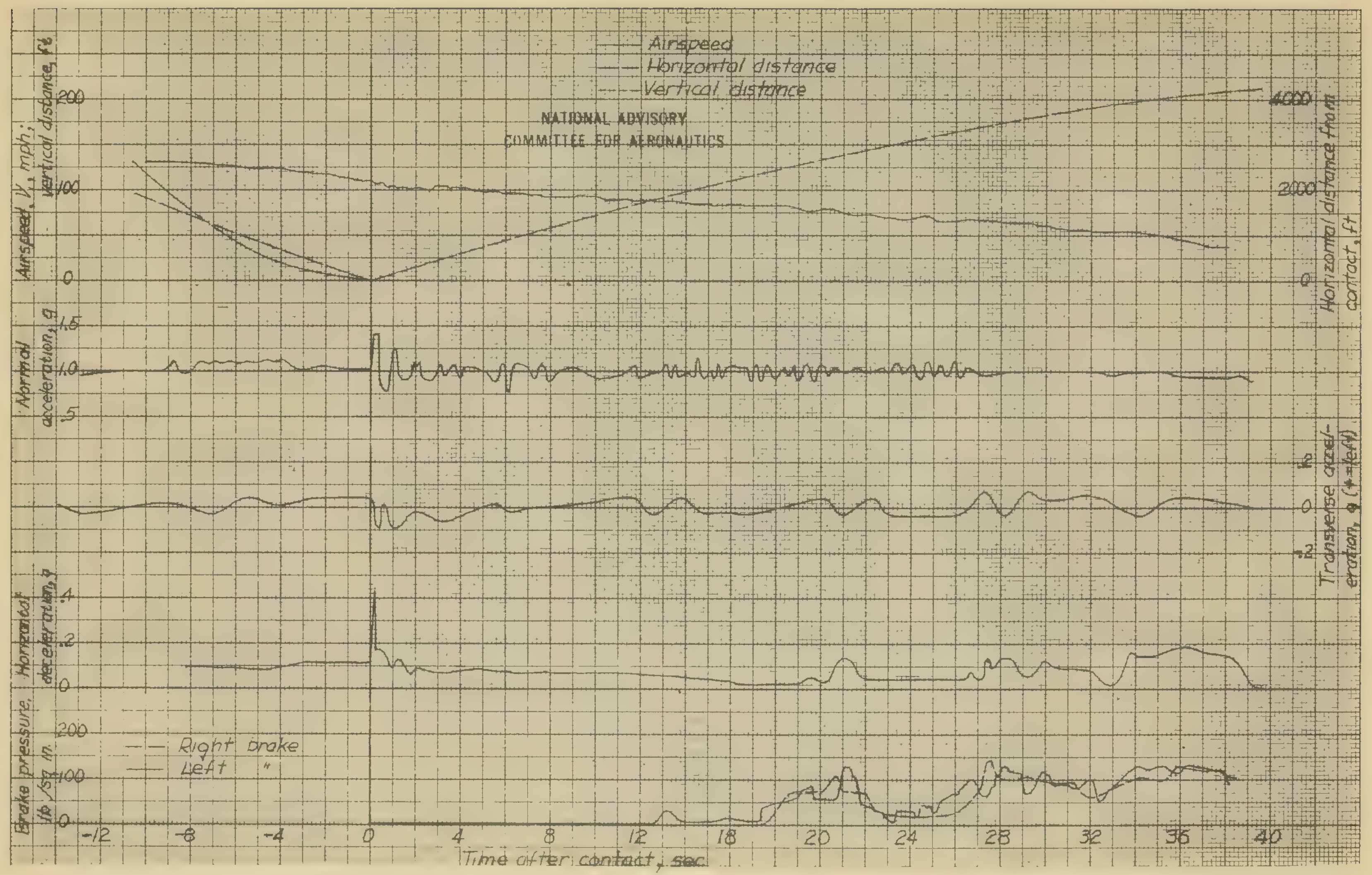
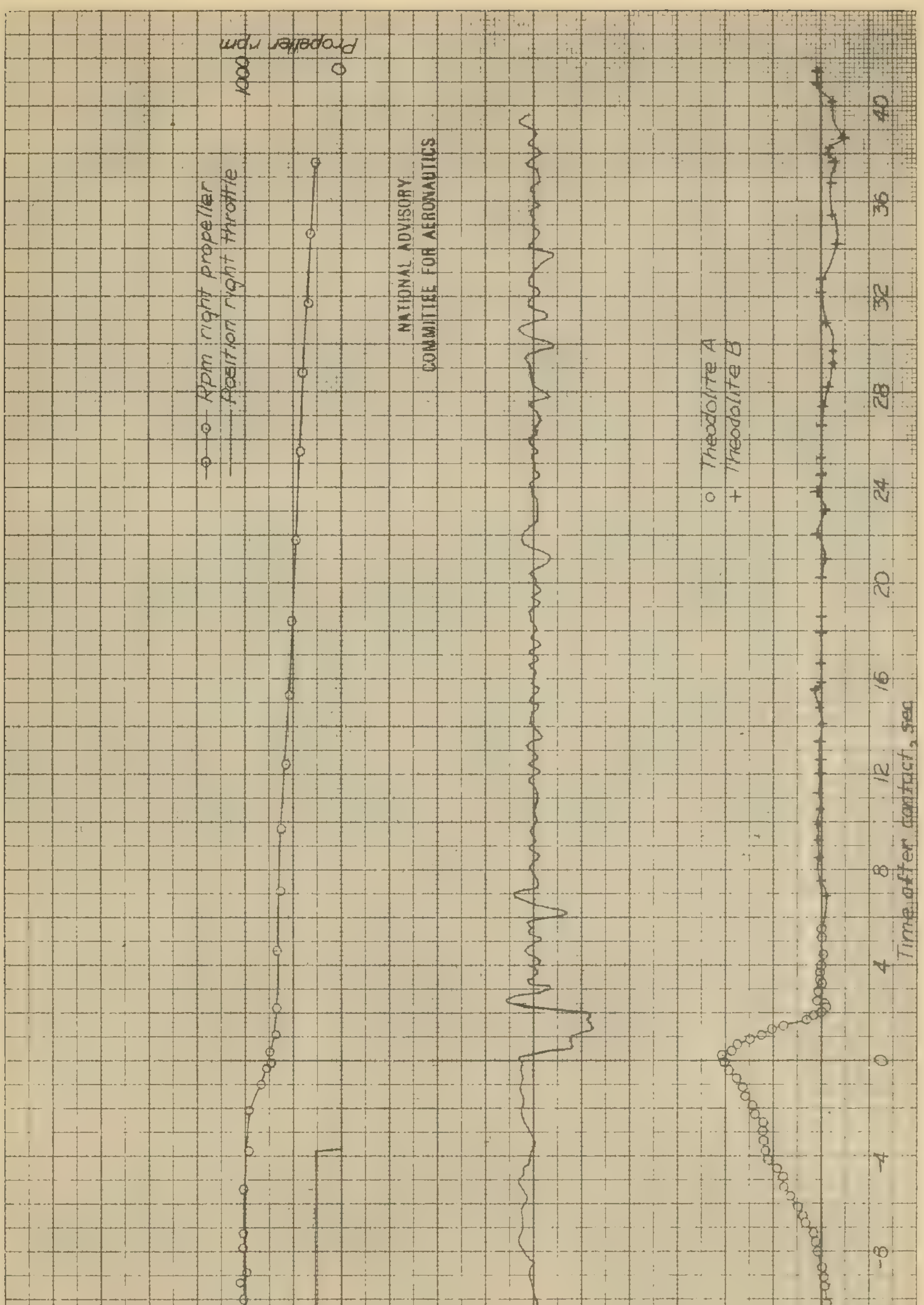


Figure 25.- Time history of landing run. B-26 airplane; landing 17, 1942 series.



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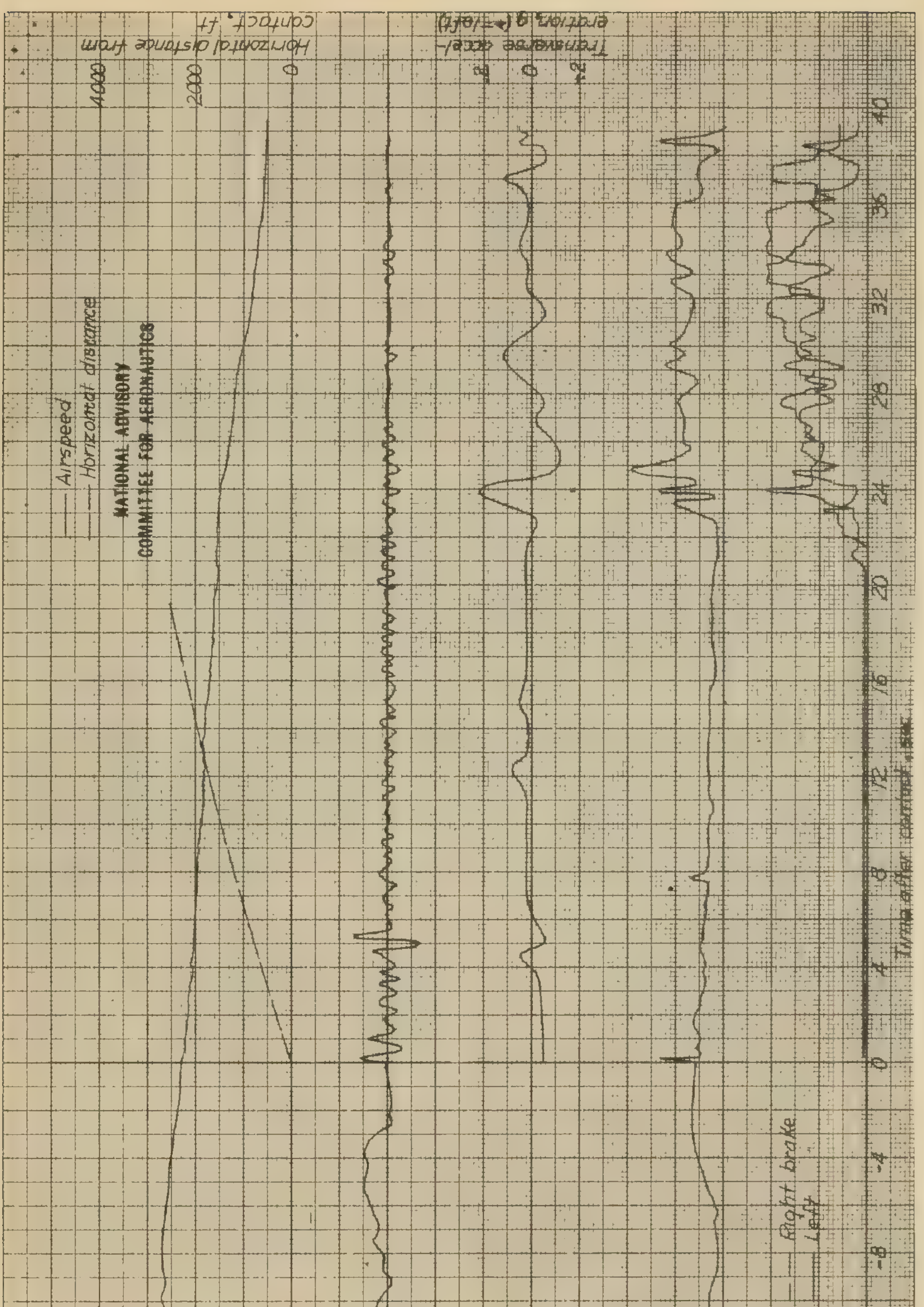
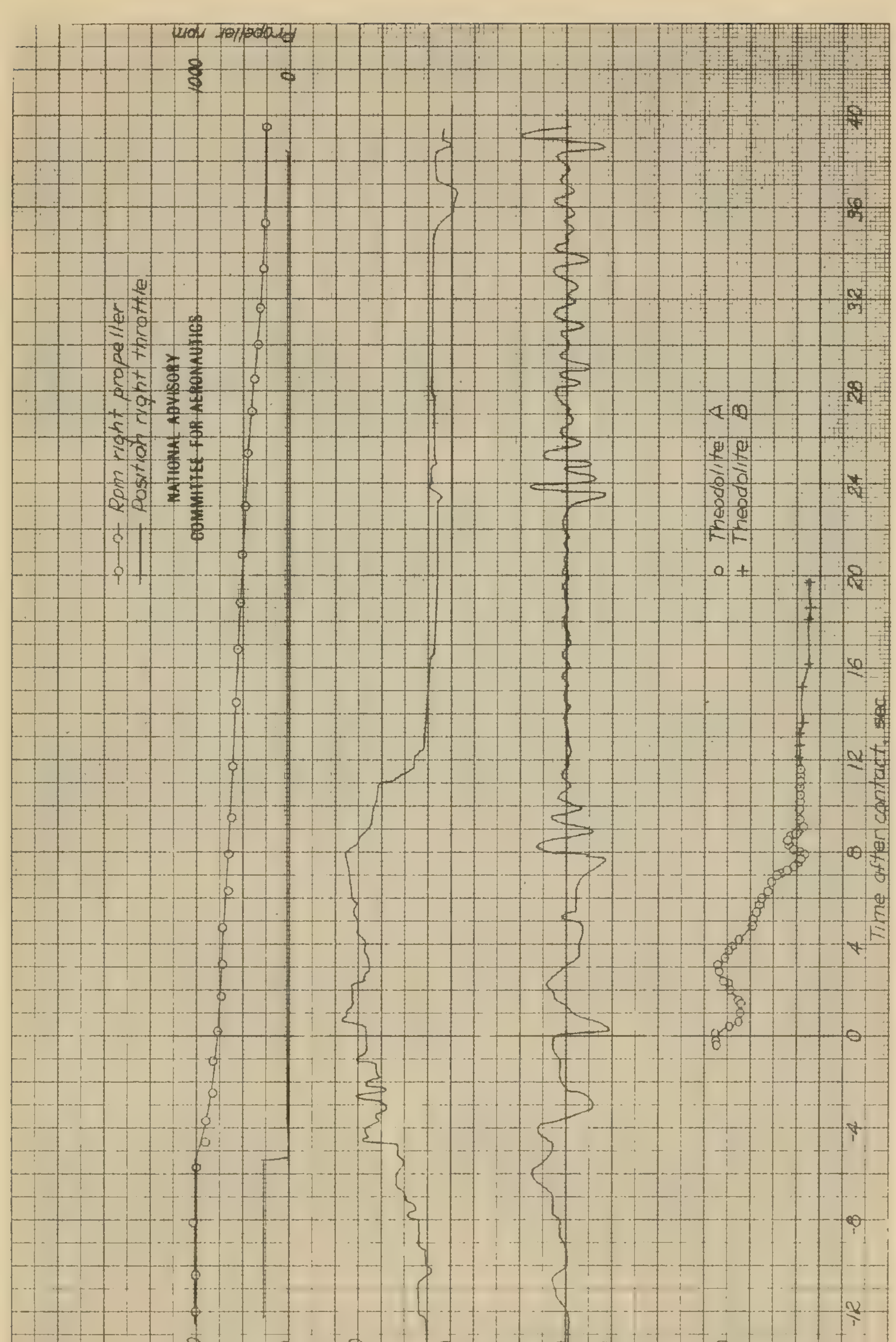


Figure 26.- Time history of landing run. B-26 airplane; landing 6, 1942 series.



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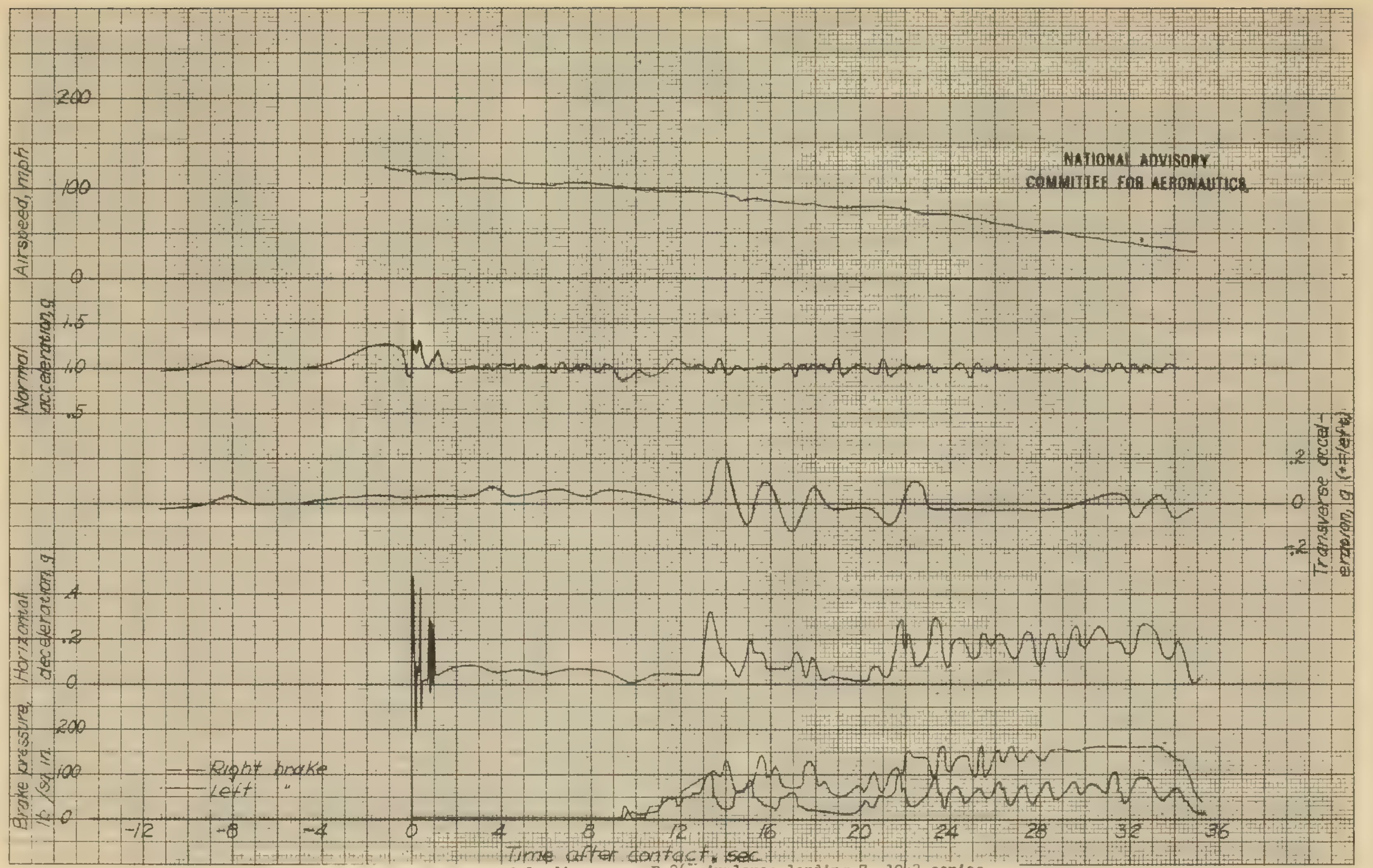
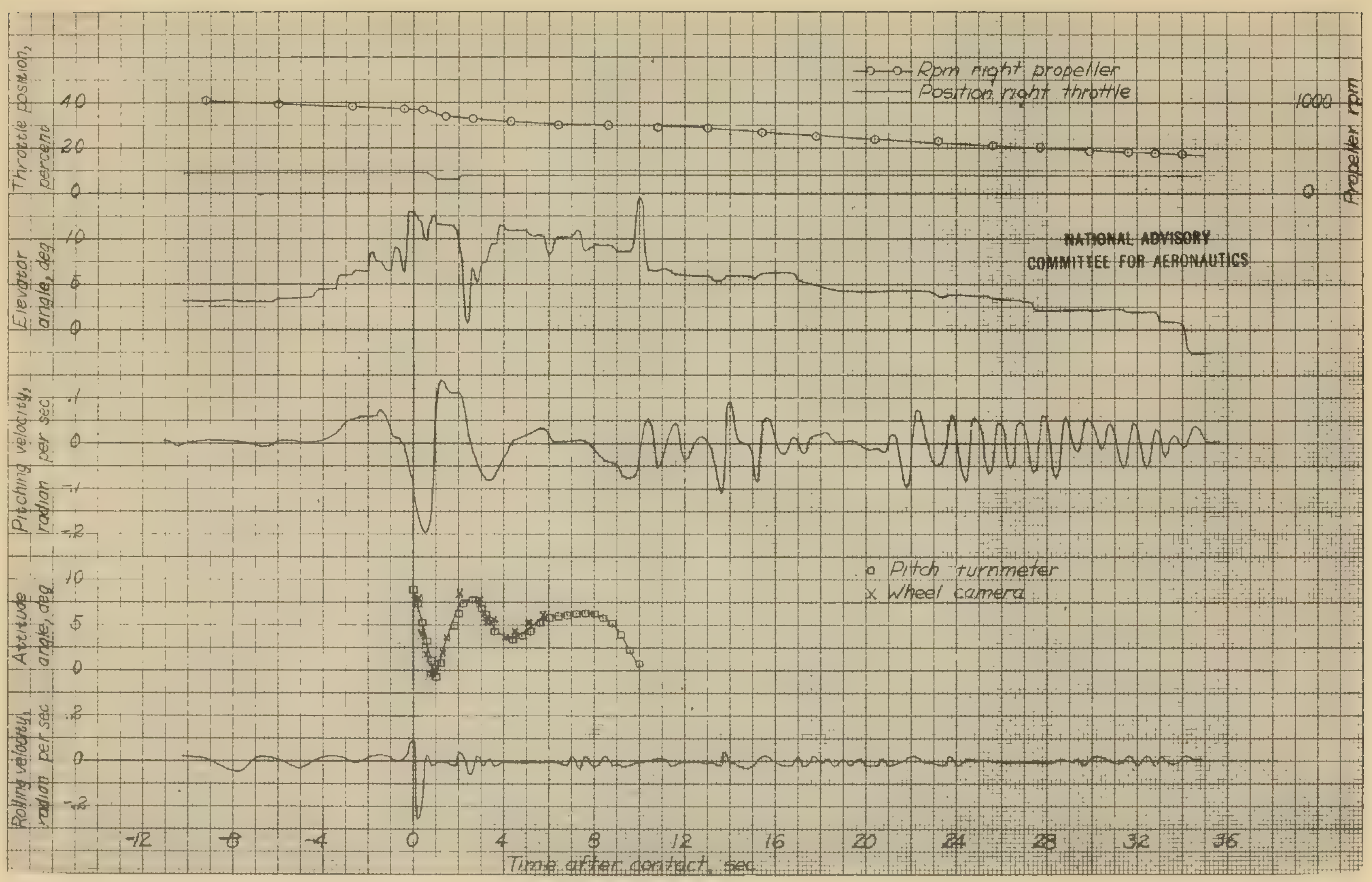


Figure 27.- Time history of landing run. B-26 airplane; landing 7, 1942 series.



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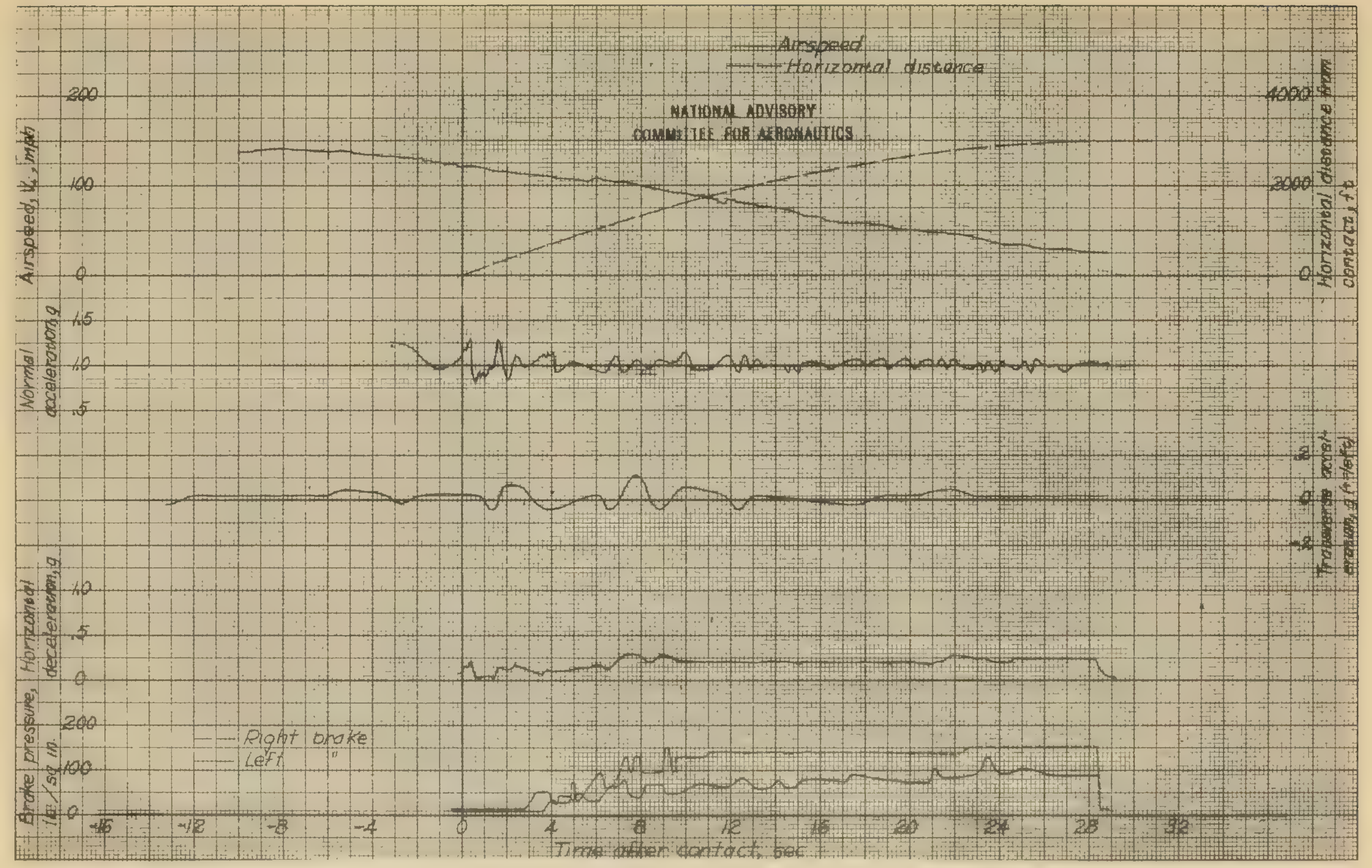
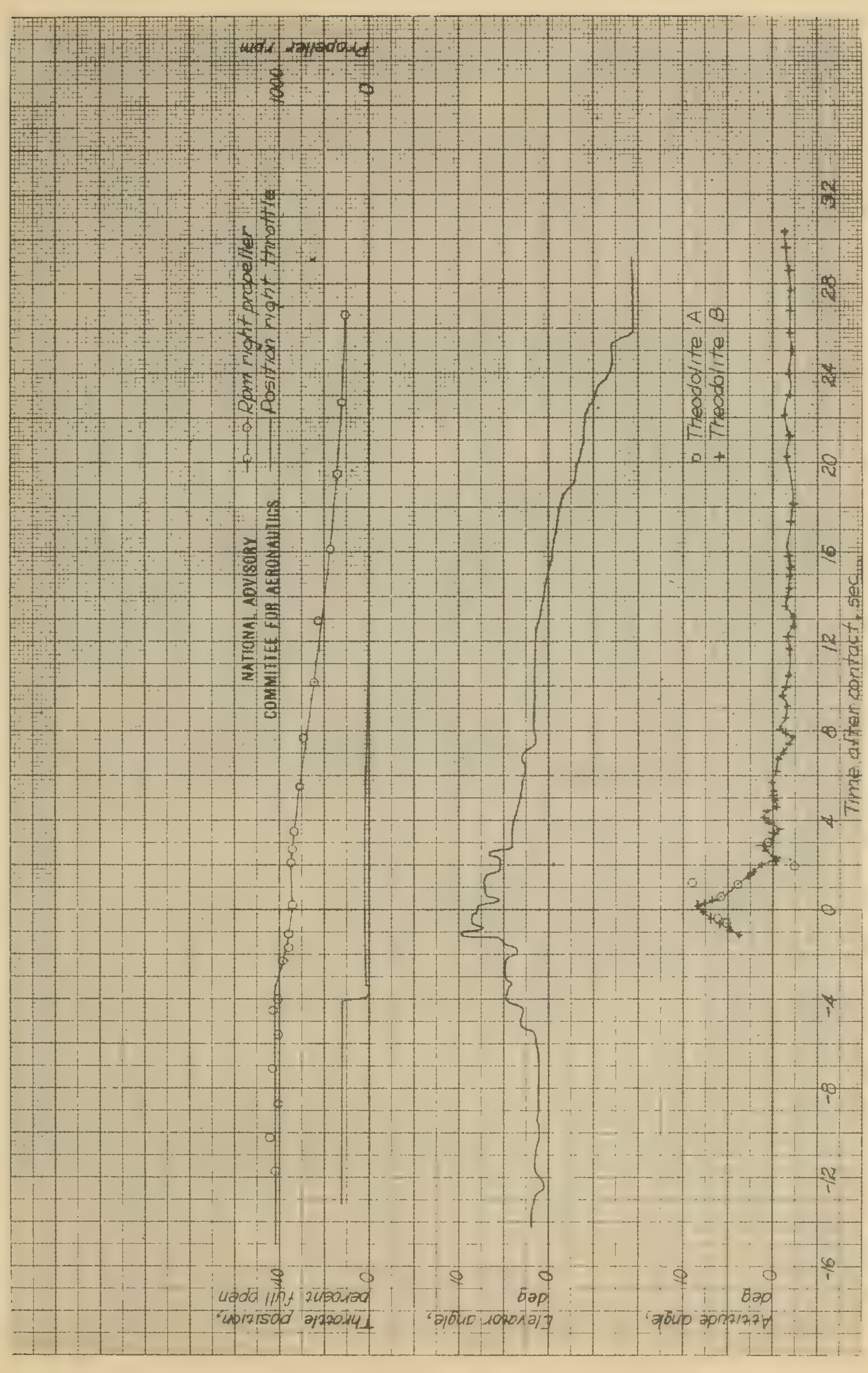


Figure 28.- Time history of landing run. B-26 airplane; landing 12, 1942 series.



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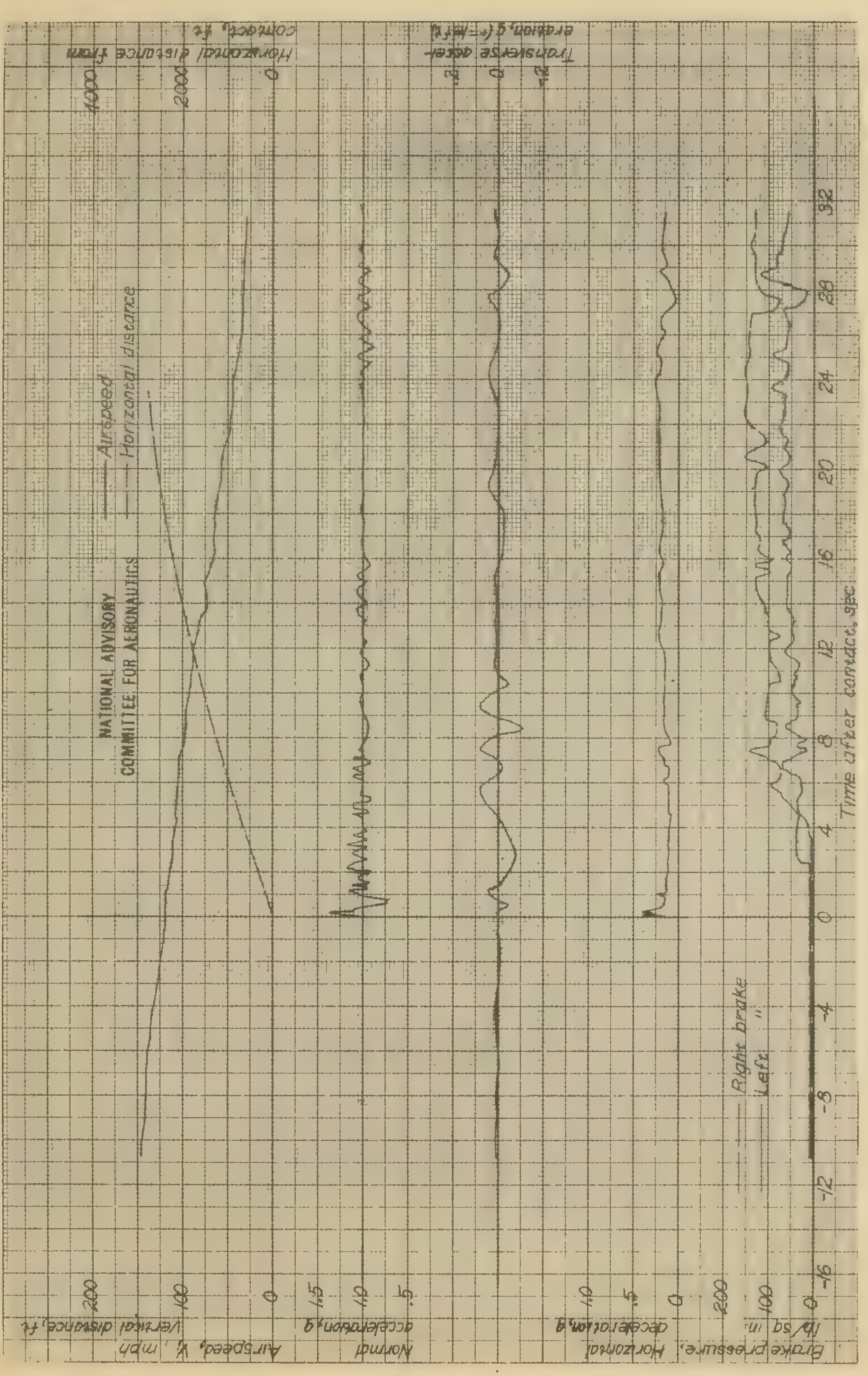
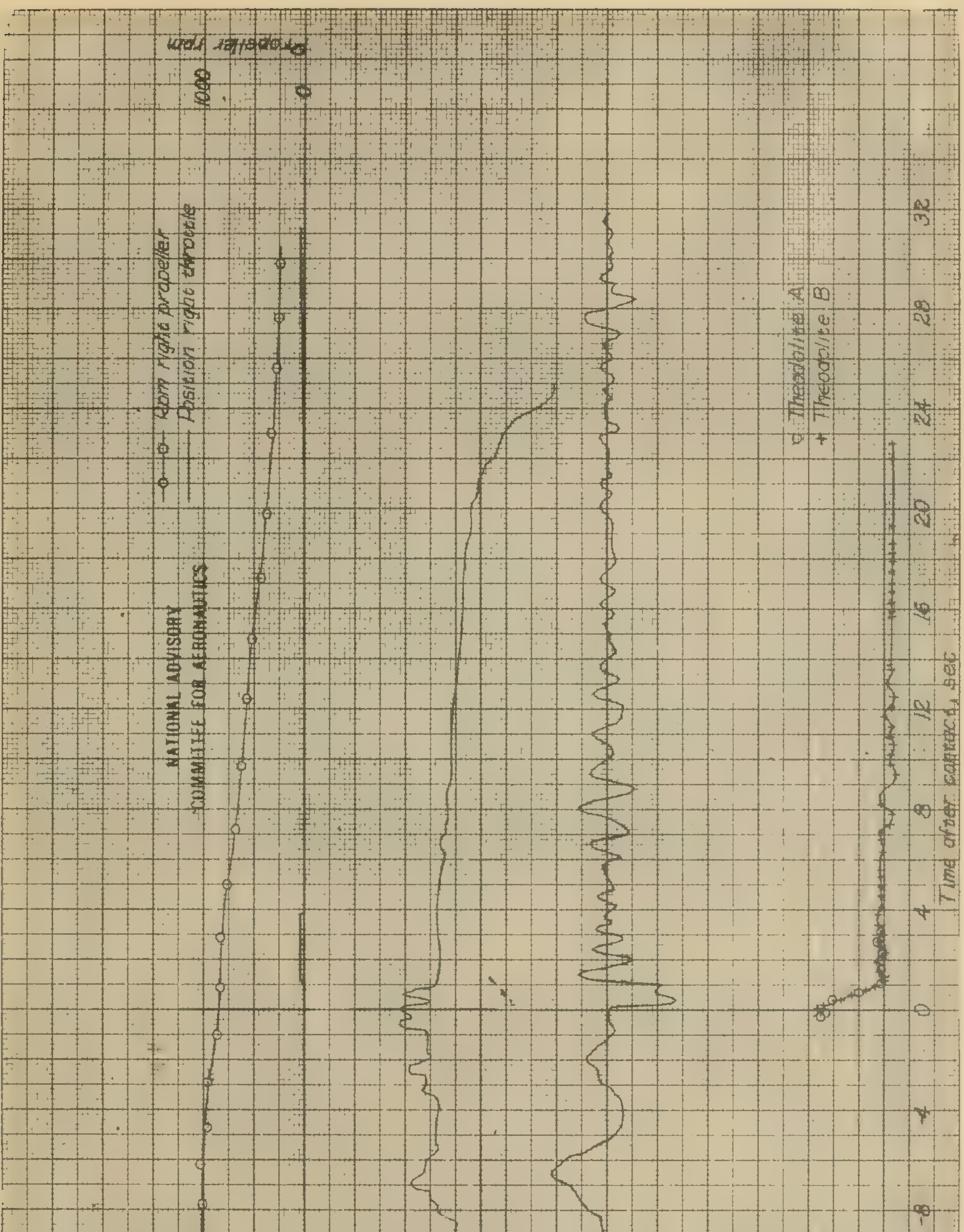


Figure 29.- Time history of landing run. B-26 airplane; landing 13, 1942 series.



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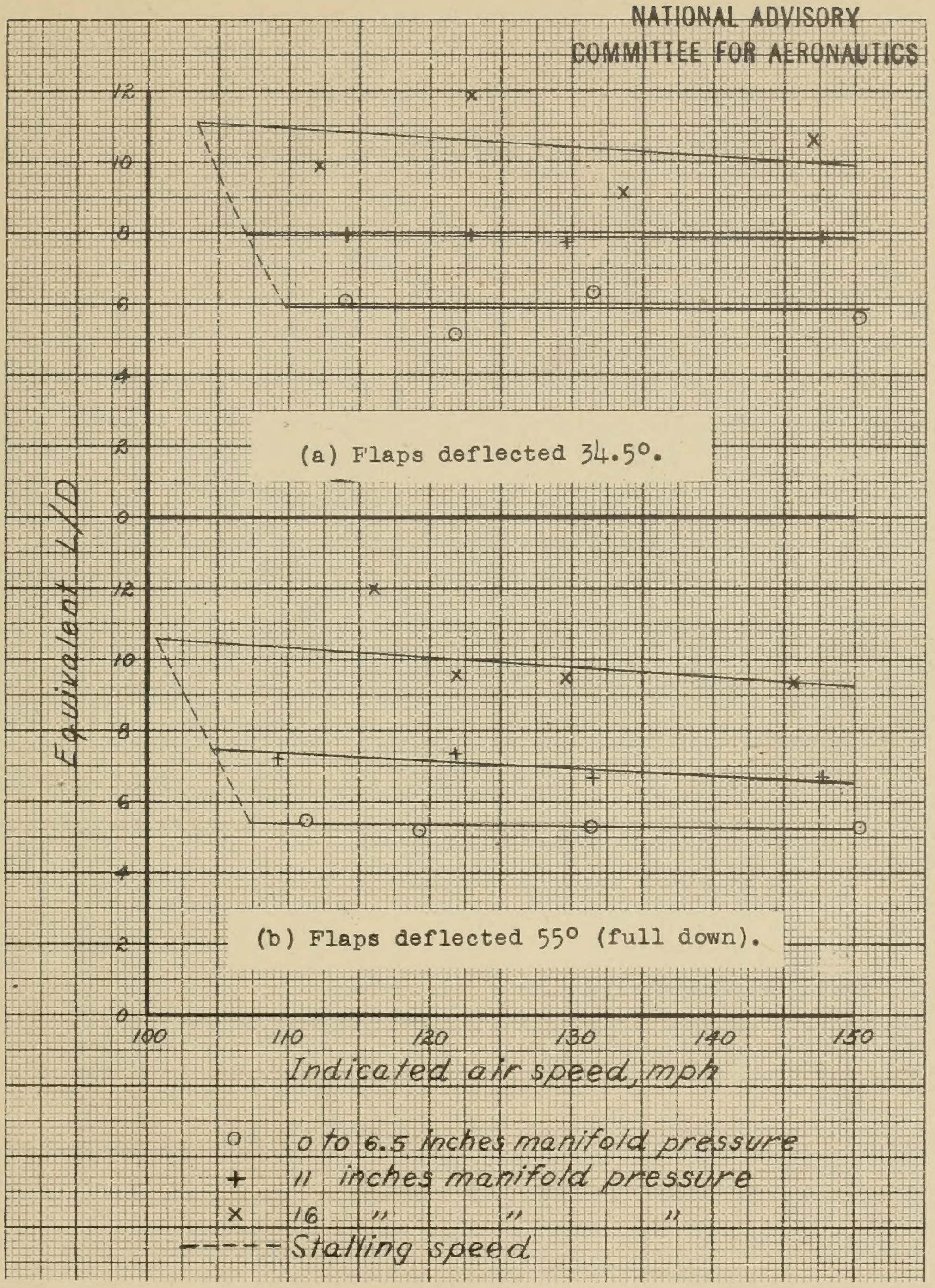

Figure 30.- Equivalent ratios of lift to drag of the Martin B-26 airplane.

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